The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association

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The Journal of
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SPECIALIZATION IN MEDICINE: WHAT IS ORTHOPAEDIC SURGERY?*

BY RALPH K. GHORMLEY, M.D., ROCHESTER, MINNESOTA

As long as the practice of medicine was an art without much background of scientific knowledge, there was little or no need for specialization. The physician with his imposing presence might control the situation, however serious it seemed. With the advancement of knowledge due to the accumulation of scientifically proved facts, the need for specialization has arisen; and specialization in medicine and surgery has developed widely in this country and in most of the world where modern medical methods are in use.

Specialization has developed because scientific discovery has wiped out many of the old concepts of illness and disease, and has made an accurate scientific knowledge of both diagnosis and treatment necessary to modern practice. The many fields of specialization in medicine are developing so rapidly that one individual cannot possibly keep up to date on all of the scientific facts available. Indeed, in some instances it is difficult for a specialist to keep up with all of the newer developments in his own field.

In attempting to come to any conclusion regarding the scope of orthopaedic surgery, one must consider its past progress, its present position, and its possible future development.

From time to time, many efforts have been made to define orthopaedic surgery. A review of the presidential addresses of the past Presidents of this Association shows that many of them were thinking about this; and in some instances they went so far as to attempt to define or outline the scope of our specialty. One must recognize the impact on our specialty of the developments in the entire field of medicine and surgery, for these have influenced its growth in many ways.

As each specialty develops some new phase of knowledge, new challenges to the old order arise. As long as we are free to advance that knowledge without the stifling influence of political control, new ideas will be developed and tried; and, as knowledge and facts gather weight and importance, new specialties will arise. The success of each group in delivering to the patient satisfaction in alleviating his ailments will be the guide to the permanency of that group in the world of medical specialists.

The borders of most specialties are not clearly defined, and orthopaedic surgery is no exception to this. Constant changes in the scope of a specialty will be noted, just as the individuals in that specialty increase their knowledge and skill in the care of certain conditions which may be called borderline. As medical knowledge advances by the development of scientific facts, specialties will ultimately tend to become more stabilized. Whether we will ever reach a stage of complete stabilization is, of course, speculative. Theoretically, such a stage might be reached when our knowledge of scientific facts has become completely evolved.

Let me emphasize my belief that, while specialties develop and specialists become more expert in their chosen fields, the need for cooperative effort by specialists in treating many individuals becomes more evident. Nothing is more pitiful than the sight of a highly

* Presidential Address read at the Annual Meeting of The American Orthopaedic Association, Colorado Springs, Colorado, May 20, 1949.

specialized individual facing some problem entirely outside the limits of his specialty, without the aid of someone versed in the care of that particular condition.

In tracing the development of the limits of our specialty of orthopaedic surgery, one must of course start with the *Orthopaedia*, a book written in 1741 by Andry, a Professor of Medicine in the Royal College and senior dean of the Faculty of Physick at Paris. Andry coined the term "Orthopaedia" and, despite many efforts to have that name changed, it has remained.

The title page of the English translation of Andry's *Orthopaedia* reveals the following:

"Orthopaedia:
Or, the Art of
Correcting and Preventing
Deformities
in
Children:
By such Means, as may easily be put in Practice by Parents themselves,
and all such as are employed in Educating Children.
To which is added,
a Defense of the Orthopaedia,
by way of Supplement, by the Author".

The scope of this treatise is broad, covering not only the prevention and correction of deformities by such means as seemed to the author to be available at that time, but also many phases of what would now be regarded as the work of dermatologists, beauty specialists, and teachers of speech correction. Whitman described Andry's work as "in no sense a scientific work, even from the standpoint of that time. It was what might be called a nursery guide; in it were considered not only the common postural deformities, but, at much greater length, external defects and blemishes, as of the hair and skin, which could not be concealed."

My reading of *Orthopaedia* leads me to be in agreement with Whitman that its scientific value is doubtful, particularly in the light of present knowledge.

At a later date Bigelow, afterward Professor of Surgery at Harvard, in a dissertation for the Boylston Prize for 1844, wrote on the question: "In what cases, and to what extent, is the division of muscles, tendons, or other parts, proper for the relief of deformity or lameness?" Bigelow stated: "It is believed that the general intention of the Committee will be fulfilled by an attempt to cover the ground now occupied by Orthopedic Surgery". In the paper Bigelow covered the following subjects: strabismus, stammering, tenotomy, club-foot, torticollis, false "ankylosis" of the knee joint, rickets, permanent flexion of the hip joint, ankylosis, lateral curvature of the spine, contraction of the hand and fingers, congenital dislocations, and subcutaneous section of the articular muscles.

In a preface to the above-mentioned paper, Bigelow stated that he had consulted the writings of Guerin and others, "especially the *brochures* of M. Guerin, who has been for some time the leading French orthopedist. . . . It is possible that M. Guerin has availed himself of the suggestions of previous writers; that, in common with other specialists, he has overestimated the importance and the efficacy of his art; that he has been indiscreet in its application; and that 'the division of forty-two tendons, muscles, etc. upon the same subject' was an audacious undertaking rather than 'a remarkable achievement'. But it should not be forgotten that the scientific acquirements and practical skill of this orthopedist are undisputed. . . ."

With the establishment of our Association in 1887, the specialty became somewhat better defined. In order to glean some facts as to the recognized scope of orthopaedic surgery throughout the years of existence of The American Orthopaedic Association, I have reviewed the presidential addresses of most of the past Presidents of the Association. In 1894, Phelps stated: "Their work [orthopaedic] was confined to the application of

appliances to overcome deformity when it was not considered a sacrilege to do so. . . . The armamentarium of the ancient *orthopaedist* was, at least, the equal of our present appliances in point of ingenuity and intricacy. And the braces used at the present time bearing the names of modern men, supposed to be modern inventions, are nothing more or less, with but few exceptions, than the revival of the old ideas of the past."

"But the science of surgery did progress, and it gradually made inroads upon the field of the *orthopaedist*, and he soon saw many of his pet deformities, which had been to him through long years a source of pleasure and remuneration, filched by the skilful and investigating surgeon. . . . Hernia unquestionably should be classified as an orthopaedic subject."

In Whitman's presidential address for 1896, entitled, "A Definition of the Scope of Orthopaedic Surgery", he suggested the following definition: "Orthopaedic surgery is that division of surgery which treats of disabilities and diseases of the locomotive apparatus and of the prevention and treatment of deformities of the framework of the body". Whitman went on to say significantly: "But this Association, as the representative of modern orthopaedic surgery, can be bound to no exclusive method or doctrine, for its object is to bring together and to concentrate individual effort in the search for truth, wherever this search may lead".

Sayre, in 1904, pointed out that: "In many parts of Europe the orthopaedist is synonymous with the instrument maker, and has the same relation to the man whom we in this country understand as an orthopaedist as the oculist bears to the ophthalmologist".

Brackett, in 1905, noted that: "One of these directions of development is particularly evident, and one day of our program has been set aside for the consideration of this branch of orthopaedic work. I am referring here to the application of orthopaedic work to adult cases, or, as it is beginning to be called, Adult Orthopaedics."

Turning to the writings of Sir Robert Jones, we find the following: "There was a time when orthopaedic surgery included a comparatively small group of cases. Lateral curvature, flat feet, rachitic distortions, club feet, and a few other congenital conditions represented the list. Apart from tenotomies and an occasional osteotomy, no other operations were indicated. The use of the knife was almost a reproach, and only followed a failure in mechanical effort. How different it is to-day, when some of the most difficult operations in the domain of surgery are included under the definition 'orthopaedic'! During the great war I had to direct—on behalf of the British Government—what was known as military orthopaedic surgery, and this involved a statement of what groups of cases ought to be included under the term.

"This definition developed into:

1. Fractures—recent, malunited, and ununited.
2. Deformities of the extremities and spine.
3. Diseases, derangements, and disabilities of the joints, including the spine.
4. Injuries of peripheral nerves."

It is my feeling, and I think the feeling of most of you, that Sir Robert's skill in organizing the work of orthopaedic surgeons in World War I and later in England has done more than any one thing to bring orthopaedic surgery to its modern status in the English-speaking world.

Platt later attributed to Sir Robert Jones the following definition of orthopaedic surgery: "The treatment by manipulation, operation, re-education, and rehabilitation, of the injuries and diseases of the locomotor system". Platt went on to point out that "a field so defined is not in the strict sense an anatomical or regional specialty. The definition hints at an intimate concern with function. It proclaims that we embrace a wide range of therapeutic techniques."

Other definitions of the scope of orthopaedic surgery have been formulated from time to time, such as that in Article I of the By-laws of The American Orthopaedic Association:

"Orthopaedic Surgery shall be considered to be that branch of Surgery the purposes of which are to prevent and correct deformity and to preserve and improve the function of the bones and joints and motor apparatus when function is threatened or impaired by defects, lesions, or disease."

Other definitions could be quoted, but it is my intent to point out the futility of writing down the scope or limitations of any specialty. A wide-awake, active group of men devoted to the principles of orthopaedic surgery will make the limits of the specialty known by their works and by their results.

It is my opinion that adult orthopaedics has developed into a more far-reaching field than the so-called orthopaedic surgery of children. From the standpoint of pure English expression, the term "adult orthopaedics" is incorrect. However, it is not my purpose to open the old argument as to whether or not the name "orthopaedic surgery" correctly defines our specialty. Through custom and usage, the term has come to mean a certain type of specialty and had best be left.

I do think that, from the standpoint of any future planning which we might undertake, particularly as to the training of orthopaedic surgeons, we should take stock of the relative importance of childhood orthopaedics and adult orthopaedics. Each is important to the other. I do not believe that a person with training only in the orthopaedic surgery of children can comprehend or handle the problems of adult orthopaedics; nor do I believe that one trained only in adult orthopaedics can comprehend or handle the problems of childhood orthopaedics. I would go further and say that one trained only in adult orthopaedics cannot understand the problems of adult orthopaedics as well as one who has also had the advantage of training and experience in the problems of childhood orthopaedics, for many of the problems of adult orthopaedics stem directly from orthopaedic conditions of childhood. This is particularly true of many of the painful hips found in adults, as well as of many other disturbances of growth and development which produce painful and disabling conditions in adult life.

In looking at the future of our specialty and of our Association, there are several facts that bear on the subject, about which we should be thinking and for which we should be planning. Whether we like it or not, it seems to me that some program of medical insurance of far-reaching scope will almost certainly be developed. With this will come a greater demand for specialists' services, and the patients will demand and get care as private patients, so that our plans for the future training of orthopaedic surgeons should point toward this. The larger "charity" services which were the background for most resident training up to the time of World War II will have to be revised to permit care of patients on a private basis.

Borderline specialities will assume certain phases of the care of patients, which have heretofore been regarded as the work of orthopaedic surgeons. Such work as physical therapy is being taken over by specialists in physical medicine, and will be taken over to an increasing extent. In some areas the supervision of brace-making is being assumed by those other than orthopaedic surgeons; and it is my belief that many practising our specialty could profit by a better understanding of the importance and the methods of brace-making. Rehabilitation, which was started by orthopaedic surgeons in World War I, may become another speciality.

As the interests of orthopaedic surgeons have tended to center more on operative procedures, some of the less spectacular but equally important phases of our specialty may have been forgotten. Perhaps these phases of the treatment of patients are better handled by others, and should not be a part of our responsibility. On the other hand, it seems to me that an understanding of them is important in rounding out the proper care of orthopaedic patients; and not only should we not give them up entirely, but we should seek to have a better understanding.

I do not believe that one can accurately and finally define orthopaedic surgery in a

satisfactory manner. Some phases of our specialty may have reached a point of stabilization and standardization which would permit definition, but many parts of the specialty are changing from decade to decade and from year to year, so that we may have difficulty in recognizing the work of a few years ago. Indeed, I think that much of the interest in the specialty would be lost, were it to become stabilized and standardized. Certainly the reason for our Association's existence is to hear from each other about methods to improve the diagnosis and treatment of orthopaedic conditions, and if a day of such standardization is reached that the specialty has nothing new to offer in methods or ideas, then our very existence as an association will be in danger of deterioration and decay.

In all our plans for the future of the specialty, the position of The American Orthopaedic Association should be one of leadership, active, alert, and decisive. Such leadership can be maintained only by an energetic group of active members, all willing to go out of their way to see the specialty develop to its greatest possibilities. Some may exert their influence through teaching, others through writing, and others through organizational work. Our active membership has remained about the same for almost twenty years, and it is time we gave thought to its enlargement, in order to take into our ranks more of the better young orthopaedic surgeons, of whom there are many.

The letter of the late Arthur G. Davis as chairman of the Membership Committee should have reminded all members of their responsibility in seeing that names of likely candidates for membership are properly proposed and sponsored.

It is my feeling that many of our members do not take the work of the Association in a serious vein. We need the active and thoughtful participation of everyone in all phases of the Association's work, in order to maintain the leadership which should be ours. This Association is not a club of honorary attainment, meant for basking in the glories of one's past, but a medium for active participation and planning by everyone now a member, and for the future activity of a number of young men whose ability is recognized and who should be taking an active part in the work.

Thus, with an enlarged and active group of men capable of leadership, we can point the way toward the development of newer ideas in orthopaedic surgery and can strive to improve it in every way, such as in practice, research, and teaching.

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CONTROL OF BONE GROWTH BY EPIPHYSEAL STAPLING

A Preliminary Report *

BY WALTER P. BLOUNT, M.D., AND GEORGE R. CLARKE, M.D., MILWAUKEE, WISCONSIN

From the Milwaukee Children's Hospital

When Phemister reported the operative arrest of longitudinal growth of bone in 1932, a new principle was introduced in the correction of excessive length and angular deformity of extremities. Previous to this time, bone-shortening operations [16] had been used to a limited extent to equalize limb length. These procedures were only slightly less extensive than those for bone lengthening [1, 2, 11] and, like them, were attended by the risk of grave complications. Growth was an uncontrolled force which had to be considered. Phemister utilized this growth factor in an operation of much less magnitude.

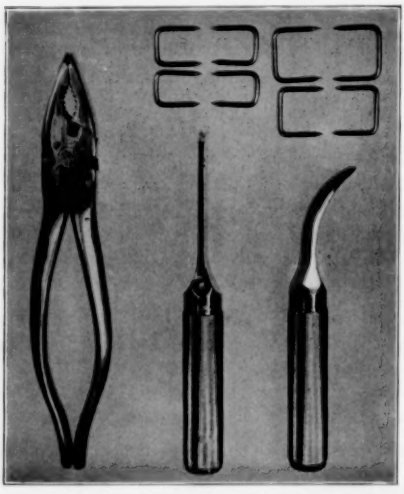

FIG. 1

Staples of three thirty-second-inch 317 M stainless steel. The legs are three-quarters of an inch long; the cross members are five-eighths and seven-eighths of an inch. Modified pliers and set help place the staples close together. The extractor is necessary for removing the staples.

Another advance was made in 1945, when Haas proposed the retardation of bone growth by a wire loop. He tried this first in laboratory animals and later in children, and proved that longitudinal growth at an epiphysis could be held back mechanically with a wire loop. Even more important, he proved that growth was resumed when the wire broke or was removed. The implications were tremendous. Instead of attempting to compute the probable future growth of both extremities and to arrest growth at the proper time, Haas suggested earlier temporary arrest. He proposed removing the retentive wire when the deformity or inequality of length had been corrected sufficiently.

Stimulated by this work of Haas, in 1944 we began to employ rigid staples of the type popularized by R. E. Burns. The method of epiphyseal stapling was reported by one of us (W. P. B.) at a meeting of the Chicago Orthopaedic Society on December 14, 1945, and was published by Hodgen and Frantz. Haas continued his experimental work on dogs, using staples rather than wire loops.[6]

Staples were used in American bone surgery in 1906 [3], and Venable and Stuck report that they had been employed in Europe long before that time. Notching or roughening them to prevent extrusion has had many ramifications. When they are to be used for growth control, it is important that they may be removed without traumatizing growing bone. Simple, smooth wire staples have been used to date. Various sizes and gauges of wire have been tried. The authors are now using three thirty-second-inch rods of 317 M stainless steel with a Rockwell hardness between 33 and 35 C. Staples are beveled on the outer sides and formed cold with dies under hydraulic pressure. Two sizes are adequate for use in the femur and tibia. The legs should be three-quarters of an inch long,

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 26, 1949.

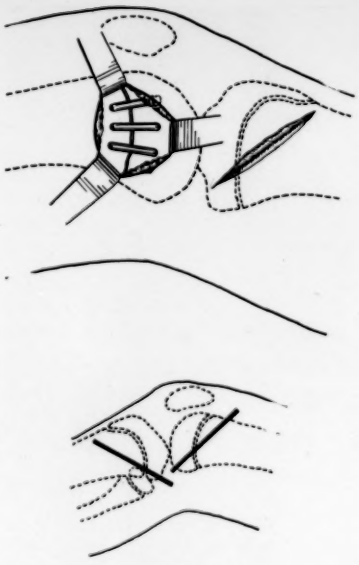

FIG. 2

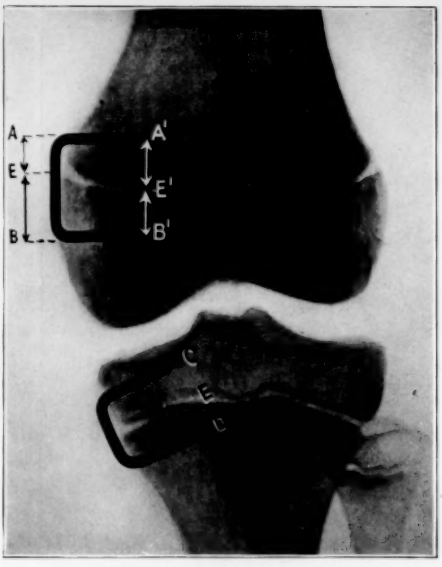

FIG. 3

Fig. 2: Oblique incisions are most satisfactory; they afford adequate exposure and cause less scarring.

Fig. 3: The epiphyseal plates undulate, as seen in both projections. (See Figs. 8-D and 10-B for lateral views.) For the legs of the staples to be equidistant from the femoral epiphyseal plate, it is necessary that AE be considerably less than EB. Then $A'E'$ will approximately equal $E'B'$. At the proximal end of the tibia, it is necessary to include more of the epiphysis, which is cancellous bone. CE should be greater than ED.

the cross member five-eighths or seven-eighths of an inch (Fig. 1). The smaller staple is used in the proximal end of the tibia, the larger one in the distal end of the femur. If the growth of the fibula or other smaller bone is to be similarly controlled, a smaller staple will be desirable.

Further experimentation may suggest a more efficient mechanical design which will still be compatible with quantity production. A physicist, a mechanical engineer, and their co-workers have been interested in the problem. Many helpful suggestions have been made by orthopaedic surgeons who have tried out the method; further comments will be most welcome. The use of a single heavy staple has been proposed frequently. This would displace more bone and would require greater accuracy of placement. The method would be less adaptable, and insertion of the staple in the proximal end of the tibia might be difficult.

Excessive bending and extrusion are mechanical problems which are easily solved by the use of an adequate number of staples. To date, no serious complication has occurred from a staple pulling out. It is a simple matter to remove, reinsert, add, or move staples. Patients must be followed closely, so that any mishap may be detected and remedied. It is wise to do the stapling while there is still sufficient growth potential to permit correction of any inadvertent angular deformity.

If one staple is inserted on each side of the end of a long bone so as to bridge the epiphysis medially and laterally, the staples will bend and break (Fig. 4-B). If two staples are used, they will bend (Fig. 6-D) and occasionally break. In this manner the growth is only temporarily or inadequately retarded. If three staples are inserted on each side of an epiphysis, growth will be stopped immediately and almost completely. The staples will usually bend slightly. There is some drifting or slipping, like wire cutting through a piece of ice, but this is negligible in relation to the shortening to be obtained. It may even be

FIG. 4-A

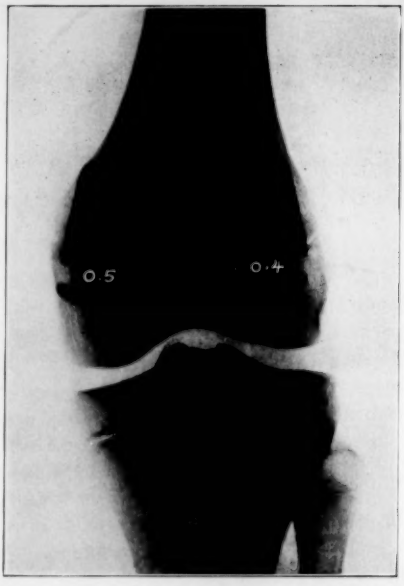

FIG. 4-B

Fig. 4-A: J. B., aged eleven. October 8, 1945, three months after stapling. One staple on each side will bend. Note that the maximum bending is in the soft epiphyseal bone.

Fig. 4-B: Three months later (January 7, 1946), the staples had broken. Three weeks after this roentgenogram, the fragments were left in as markers and new staples were inserted.

FIG. 4-C

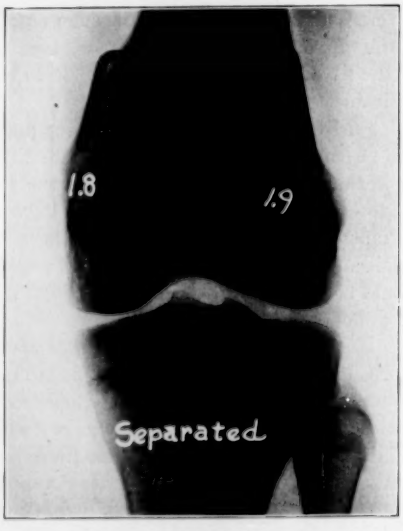

FIG. 4-D

Fig. 4-C: May 6, 1946. Four months later, and three months after insertion of new staples.

Fig. 4-D: May 24, 1948. Twenty months after removal of the last staples, and twenty-seven months after insertion of the second group of staples. There had been 1.1 centimeters of growth since Fig. 4-C was taken: 0.3 centimeter occurred during the time the staples were in place (slippage and bending); 0.5 centimeter in the first three months after removal; and only 0.3 centimeter in the next thirteen months. In the next ten months there was no growth, although this roentgenogram shows that the epiphyseal plate is just closing.

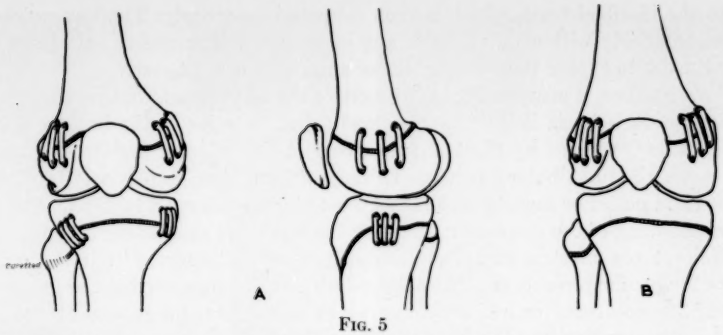

FIG. 5

Diagrammatic representation of the control of linear growth. Three staples are a unit.
A: Total involvement. Femur and tibia are both too long.
B: Femoral involvement. Only femur is too long.

desirable to allow some slipping, so as to maintain the viability of the epiphyseal plate. Complete arrest might cause premature epiphyseal closure. More efficient staples will be tried out experimentally.

The authors' routine is to use three staples as a unit unless there is a reason for another combination. Interesting growth changes can be obtained. In a long lower extremity with knock-knee, one may put three or four staples on the medial side and one or two on the lateral aspect. The drift on the lateral aspect will equalize the knock-knee at about the time the inequality of length is overcome.

OPERATIVE TECHNIQUE

The extremity is shaved and washed from ankle to groin on the day preceding operation. A tourniquet is applied at the mid-thigh; the knee is prepared surgically; and the foot is wrapped in a small sheet. The knee is supported on a block in flexion of 30 to 70 degrees. Medial and lateral incisions, 5 to 8 centimeters long (depending upon the amount of subcutaneous fat) are made obliquely through the skin and subcutaneous fat centering over the epiphysis to be stapled. Above the knee, the incisions should slant from anterior-proximal to posterior-distal; below the knee, from posterior-proximal to anterior-distal (Fig 2). The scarring is less if two incisions are used instead of a single long one, for exposing simultaneously the femoral and tibial epiphyses. The deep fascial layers are split in the direction of their fibers and the periosteum is exposed. Mobile soft parts must not be impaled.

Staples may be inserted "blind" without actually cutting through the cartilage cap and exposing the epiphyseal plate. Roentgenograms in two projections are imperative. After the position has been verified, it is often a good plan to cut the periosteum and cartilage along the cross members of the staples and to sink the staples flush. Some surgeons will prefer to incise the periosteum and overlying cartilage and raise two flaps, so as to expose the epiphyseal plate. In children under ten, thick flaps are necessary. It is not desirable to bury the staples deeply, if they are to be removed.

The easiest approach is at the medial aspect of the distal femoral epiphysis. With the knee flexed, the vastus medialis need not be split. It is displaced anteriorly, while the hamstring tendons fall posteriorly. The movable fascial layers are split in the direction of their fibers. By sharply flexing the knee, the posterior aspect of the femoral condyle may be reached without difficulty. By straightening the knee and strongly retracting the vastus, staples may be placed anteriorly.

Exposure of the lateral aspect of the distal femoral epiphysis is only slightly more difficult. It is a mistake to incise the fascia lata with the knee extended. With the knee flexed, the thin dorsal expansion of this fascial layer may be split longitudinally, just

dorsal to the iliotibial tract, which is then retracted posteriorly. The vastus lateralis is displaced anteriorly without division of any of its fibers. The mobile soft parts may be retracted easily to expose the condyle, either anteriorly or posteriorly.

Below the knee, it is necessary to cut more of the soft tissues. On the lateral aspect of the tibia, the deep fascia is split longitudinally, just anterior to the head of the fibula. The incision is developed by elevating the fibers of the extensor digitorum longus from the fibula and the tibiofibular ligament. Through this incision, staples may be inserted on the lateral and posterior aspects of the tibia. Posterior staples must be tilted anteriorly, to keep the distal leg of the staple from missing the bone and protruding into the popliteal space. If the staples must be placed anteriorly, they are best inserted "blind", just posterior to the tonguelike projection of the epiphysis. The thick ligamentous tissue can then be split along the cross member, and the staple can be buried. It requires some care to keep the staples from protruding into the knee joint.

It should be noted in the roentgenograms that the epiphyseal plates undulate. To obtain maximum efficiency, the staples are placed slightly farther distally on the femur than would appear necessary from the peripheral level of the cartilage; at the proximal end of the tibia, the center of the staple must be slightly proximal (Fig. 3). At the distal end of the femur, anterior or posterior staples must be inserted somewhat proximal to the middle ones (Fig. 5).

While the roentgenograms are being developed, the proximal fibular epiphysis is exposed by elevating the periosteum on the anterior aspect. The peroneal nerve is guarded by bone-elevating retractors. One-half or more of the epiphyseal plate is curetted away. A few bone chips from the metaphysis may be inserted into the defect. It is certainly undesirable to let the fibula grow too long, but there is no particular disadvantage in having it slightly short. Simple curetting has proved so satisfactory that the writers have not used staples at this epiphysis, although they would be preferable in a young child. Staples of the standard sizes are too large for this purpose.

On the medial aspect of the tibia, an oblique incision splits the anterior fibers of the pes anserinus. The tendinous expansion of the sartorius and gracilis may be retracted posteriorly for anterior or medial insertion, but cannot well be mobilized for posterior placement.

If the surgeon wishes, and particularly if the staples are to remain in permanently, the epiphyseal plate may be exposed. A one-inch

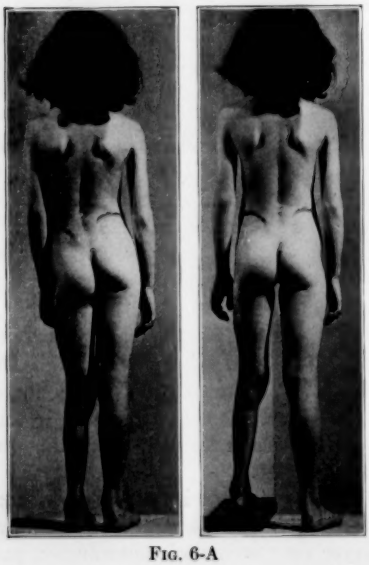

FIG. 6-A

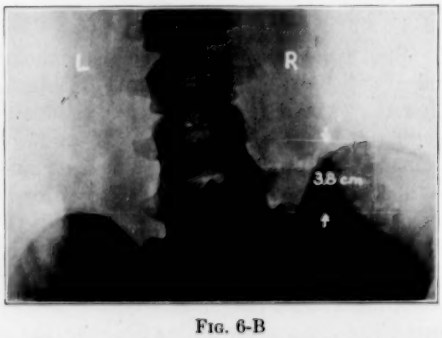

FIG. 6-B

Fig. 6-A: H. H., aged nine. April 3, 1946. Patient has short left tibia following poliomyelitis; triple arthrodesis of left foot has been done. Elevation of one and one-half inches fails to level the pelvis.

Fig. 6-B: April 3, 1946. Roentgenogram, by White technique, demonstrates total shortening, pelvic tilt, and functional curve.

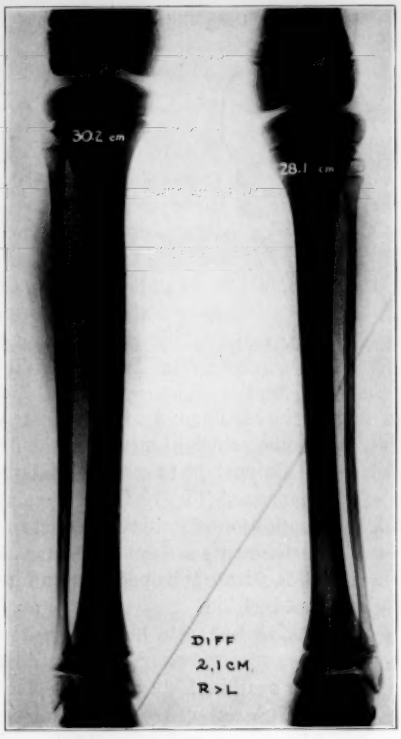

FIG. 6-C

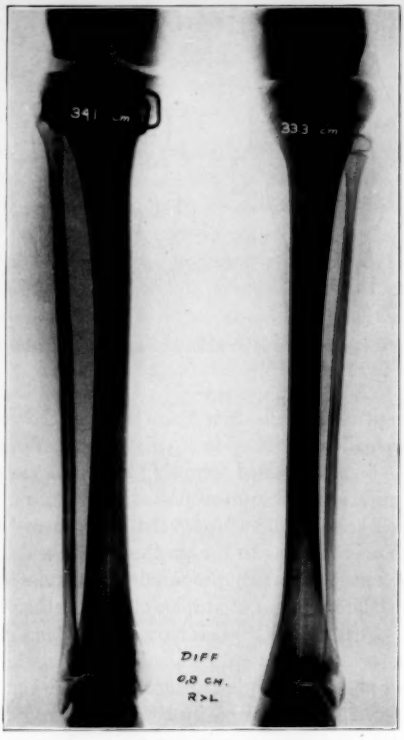

FIG. 6-D

Fig. 6-C: April 3, 1946. Roentgenogram at six-foot distance, before stapling.

Fig. 6-D: December 11, 1948. Roentgenogram at six-foot distance, thirty months after stapling. Staples have bent. Three staples should have been used on each side instead of two.

Fig. 6-E: December 11, 1948. Six-foot roentgenogram, by White technique, indicates that total shortening had been reduced to 2 centimeters. This is almost enough correction, because of the drop-foot on the left.

Fig. 6-F: December 11, 1948. Thirty months after stapling, gait had improved. A lift of three-quarters of an inch completely corrects the pelvic tilt.

FIG. 6-E

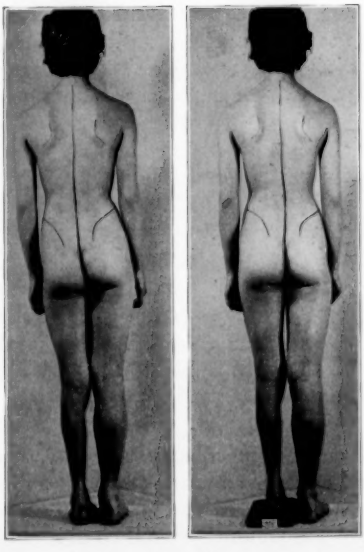

FIG. 6-F

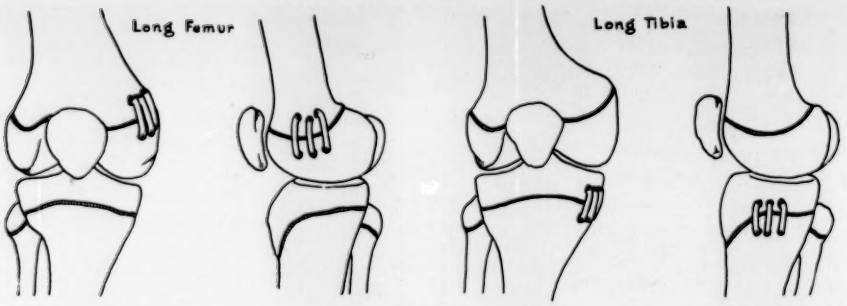

FIG. 7

Diagram of staples placed to correct knock-knee. Femoral and tibial epiphyses could both be stapled in an extreme case.

longitudinal incision is made through the periosteum and the cartilage cap. Short crosscuts are made at both ends of this incision. With a thin osteotome, which is curved on the flat, two flaps are raised, exposing the epiphyseal cartilage. It is important to center the staples accurately in the anteroposterior direction. Displacement forward (Fig. 10-C) will result in back-knee, while a backward location will produce the opposite deformity. Three staples are driven so as to bridge the epiphyseal line. Special instruments are not necessary. An inserter or specially prepared pliers and a set (Fig. 1) will facilitate the operation and permit the insertion of staples close together through a small incision.

After all of the staples are in place, roentgenograms are taken in both the anteroposterior and lateral projections. A true lateral view is necessary to prove that both legs of a posterior staple are actually in the cortex of the femur or tibia. If any staple is placed incorrectly, it may easily be withdrawn. For this purpose, a special wedge-shaped, curved-on-the-flat extractor is desirable. The extractor should be driven under the staple, so as to avoid damage to the epiphyseal plate. The staple is then reinserted with the other staples as guides. Roentgenograms in two projections are taken again.

After the exact location of the staples has been verified, the wounds are closed in layers. As is customary following epiphyseodesis, a cylinder cast was applied for three weeks in our earlier cases. When short oblique incisions are used, this is not necessary.

By experience, the authors have learned:

1. To use staples of appropriate size;
2. To use three staples as a basic unit;
3. To study carefully the undulations of the epiphyseal plate in the preoperative roentgenograms (Fig. 3);
4. To obtain accurate roentgenograms in both anteroposterior and lateral projections *in the operating room.*

REMOVAL OF THE STAPLES

The old incision is opened or the scar is excised. If the staples have been driven through the periosteum, it is an easy matter to locate and remove them. If the staples have been buried and considerable bone has grown over them, removal is more difficult than insertion. The periosteum is elevated and chips of bone are removed tangentially with a chisel. Probing with a straight needle is sometimes helpful. If the staples are not discovered immediately, they should be located by roentgenograms. Markers are inserted and roentgenograms taken in the anteroposterior and lateral projections. More bone may then be removed, but mutilation of the epiphysis is not necessary. No growth arrest has been encountered, even if considerable bone has been removed. Care has been taken not to replace bone, which would produce a grafting effect across the epiphysis.

After the cross member of a staple has been uncovered, it is an easy matter to drive the wedge-shaped extractor under it and to "break out" the staple. Extraction with a periosteum elevator or any ordinary instrument is difficult.

COMPLICATIONS

Before the necessity of biplane roentgenograms in the operating room was appreciated, avoidable errors in technique were made. One staple was left protruding into the knee joint. It was removed and reinserted without subsequent ill effect. On several occasions, the posterior staple at the proximal end of the tibia or the distal end of the femur was wrongly placed. One leg of the staple failed to engage the sloping cortex of the bone. Aiming the staple toward the center of the bone will avoid this mistake, and will also prevent the points of the staples from protruding into the popliteal space. Any such error in technique should be discovered in the operating room; it is easily remedied by reinserting the staple. If later roentgenograms show that one of a group of staples does not change while the adjacent staples start to spread, there is proof of improper insertion of the staple with parallel legs.

Angular deformity and overcorrection have occurred when the patients have failed to report regularly for observation. The serious deformities reported by Straub, Thompson, and Wilson; Regan and Chatterton; and others have not been observed. Deformities which are produced by mistakes of prediction or of technique may be corrected without osteotomy by rearranging the staples, if the child continues to grow.

DISCUSSION

In 1862, Hueter noted the relatively greater growth of bone structures which are under diminished compression. Seven years later, Volkmann laid the foundation for epiphyseal stapling when he referred to the observation of Hueter and added that abnormal differences of compression cause unequal, asymmetrical growth of a joint. On the side where pressure is abnormally increased, growth is retarded.

There is no doubt that growth may be arrested by epiphyseal stapling (Figs. 6-A to 6-F, 8-A to 8-D, 9-A to 9-E, and 10-A to 10-D), and that growth is resumed when the staples have been removed (Figs. 4-A to 4-D). Two questions were raised by Haas[6] with regard to the progress after removal of the staples: (1) Is growth less rapid than would ordinarily be expected? (2) Is growth terminated earlier? We can answer these questions in part.

In most children, prolonged observation after removal of the staples will be futile, as growth will stop within a year or two. In thirteen cases, the staples have been removed for six months or longer. It might seem expedient to chart the subsequent epiphyseal growth as compared with that on the "normal" side. Of the thirteen cases, however, only seven operations were performed primarily for linear deformity and six for angular deformity. In several cases, both deformities were

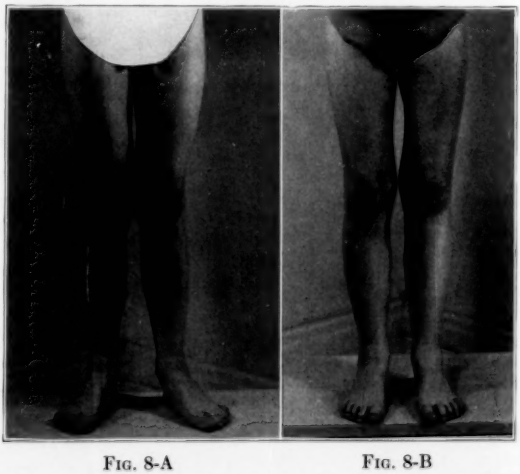

FIG. 8-A FIG. 8-B

Fig. 8-A: G. O., aged nine. October 11, 1948. Photograph of patient with hereditary knock-knee, before stapling.

Fig. 8-B: February 7, 1949. Three months after stapling, there was complete correction of knock-knee.

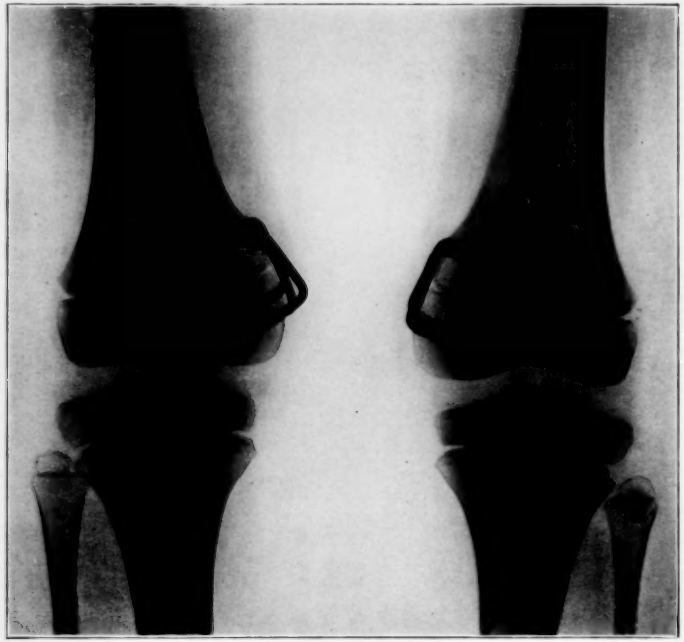

FIG. 8-C

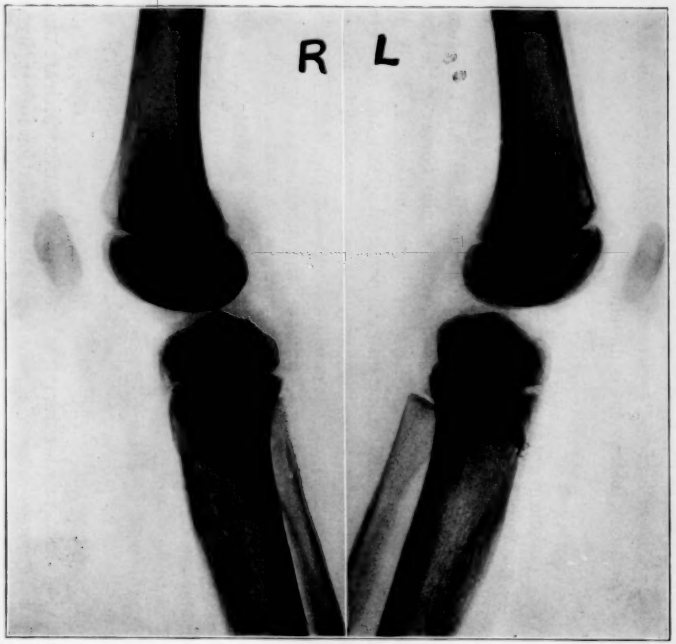

FIG. 8-D

February 7, 1949. Valgus had been corrected. Staples were ready for removal.

present and were corrected simultaneously. Even if we consider only the linear cases, the figures become meaningless. Either the stapled side is abnormal (osteomyelitis, Figs. 9-A to 9-E), or the opposite side is atrophic (poliomyelitis, Figs. 6-A to 6-F), has a mechanical derangement of the epiphysis (trauma), or in some other way is vitiated as a control.

More significant is the observation of the six cases of angular deformity in which stapling was done on one side only. All of the extremities were symmetrically aligned with the opposite side at the time the staples were removed (Figs. 8-A to 8-D and 10-A to 10-D). There has been no change of alignment since.

In two cases, markers were left *in situ* after removal of the staples. In one girl, aged fourteen, the distal femoral epiphysis grew 5 millimeters in the first three months. In the following thirteen months it elongated only 3 millimeters. In the next ten months there was no growth on either side, although the epiphyses remained open until the termination of this period. A second girl, aged seven, grew 2.3 centimeters at the distal femoral epiphysis in the first ten months after removal of the staples. Such variations are probably due to temporary growth spurts and not to the previous stapling.

It is difficult to confirm clinically the excellent experimental work of Haas[6]. We agree when he says: "It is difficult to determine definitely whether or not growth is as active after temporary retardation by a wire or staples. It was not so active as on the normal side, but it is possible that injury to the circulation and trauma to the plate disturbed the growth. There was evidence of premature closure of the plate in some of the experiments."

FIG. 9-A

D. G., aged seven. November 7, 1946. Chronic osteomyelitis of right tibia with overgrowth, valgus knee, and valgus foot.

Growth is "not so active as on the normal side" in his dogs, but in children it is not infrequently *more* active. An epiphyseal plate which has become thin as a result of stapling rapidly regains its former thickness after removal of the staples. Growth is temporarily accelerated, probably due to the stimulus of the operation for removal of the staples. There should be nothing in this operation to retard growth. Significant epiphyseal injury has not been observed. Haas's staples were very large for the size of the bones. The trauma to the epiphysis which he mentions need not occur in children. His observations on unilateral stapling in puppies, with large staples, are not applicable when three-quarter-inch staples are used in children. Clinically, the effect on longitudinal growth is less and the correction of angular deformity is more than Haas observed when his unilateral staples extended clear across the bone.

In our early personal communications, no untoward epiphyseal closures were reported. We have had none yet. Whether staples are removed or left *in situ*, epiphyses which have been operated upon usually fuse from two to six months early. This acceleration of a developmental process is probably due to the stimulus of the operation and not specifically to the stapling. It comes at a time when growth on the other side is minimal or absent, and is not very significant.

Those who want tables and graphs to prove the rate of growth after removal of staples should consider the following example: A ten-year-old child breaks one femur in the middle third. Healing occurs with bayonet apposition and one centimeter of shortening. One of three things may happen:

1. The bone will probably overgrow, due to the stimulus of the fracture. Accurate measurement at the end of six months will show that the femora are about equal in length.

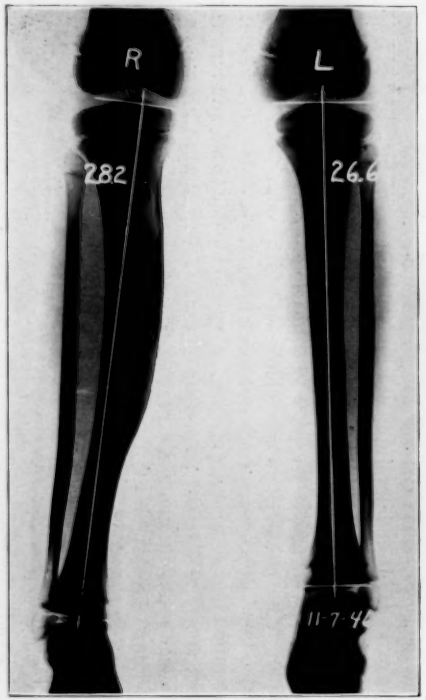

FIG. 9-B

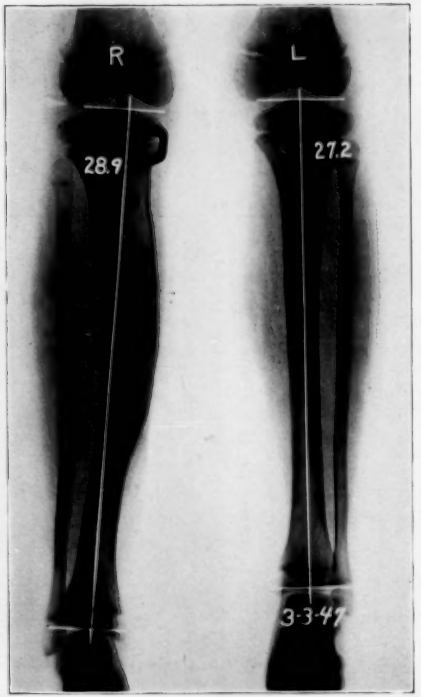

FIG. 9-C

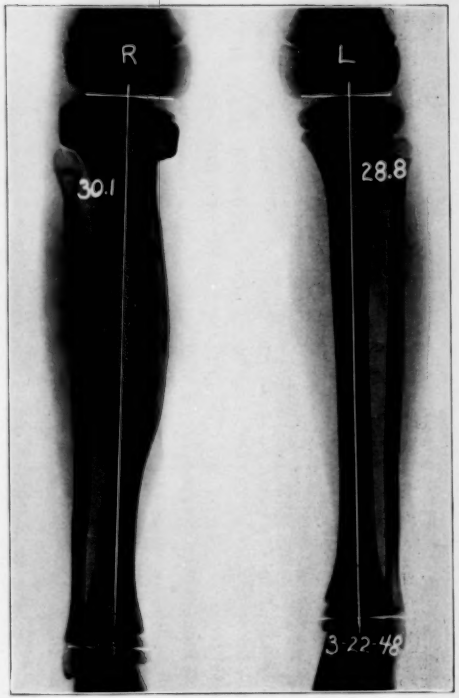

FIG. 9-D

Fig. 9-B: November 7, 1946. Anteroposterior roentgenogram shows angular deformity on right side. The difference in length of the tibiae was 1.6 centimeters.

Fig. 9-C: March 3, 1947. Four months after stapling, the angular deformity had been corrected. The linear deformity was unchanged. Staples were then inserted on the lateral aspect.

Fig. 9-D: March 22, 1948. One year after second stapling, linear deformity had been corrected by 0.3 centimeter.

2. There may be no overgrowth of bone, but persistent shortening of about one centimeter.

3. There may be excessive overgrowth of bone, so that the injured femur is as much as one inch too long. When the results of a simple fracture in a normal bone vary so much, we can attach little value to statistical studies of growth increment in abnormal bones.

The best way to test growth after the removal of staples is to watch a case of idiopathic knock-knee in a boy of ten to twelve years. In a boy of this age there is little tendency to further change in angulation. If three staples are inserted on the medial aspect of each distal femoral epiphysis, the deformity will be completely corrected in from three to eight months (Figs. 8-A to 8-D). The exact time depends upon the extent of the deformity and the rate of growth during the control period. If the staples are then removed and photographs and roentgenograms are taken, a record of the straightness of the lower extremities is established. If the existing state is maintained, then we have clinical proof that essentially normal growth of the epiphysis has been resumed. The untouched lateral aspect of each epiphysis acts as a control. Two such cases have been observed for ten months or longer without change in alignment. If several such cases are observed until growth has ceased, we shall have valuable proof to report in a future paper.

"More difficult than the actual technical procedure is the decision as to when the operation should be performed and which epiphyses should be fused." This was the decision of Wilson and Thompson, after describing an elaboration of Phemister's technique with the removal of large grafts, curetting, and cauterization of much of the epiphyseal plate. Stapling simplifies the operation, and it also answers their questions.

The operation should be performed several years earlier than appears necessary from the actuarial charts. It should be performed at a time that is convenient to the patient; the exact date makes little difference. When the deformity has been corrected, the staples are removed.

FIG. 9-E

December 18, 1948. Nine months later, additional correction of 0.3 centimeter had been obtained (total correction of the tibiae of 0.6 centimeter).

The decision as to which epiphysis to staple is no longer a serious matter. Both the proximal tibial and the distal femoral epiphyses should be stapled. When the individual bone is of the proper length, the staples are removed.

Sixteen years after the publication of Phemister's article, there is still no unanimity as to a method of estimating growth. White's simple annual increment [17], the percentage factor of Wilson, Thompson, and Straub [13, 18], and the various tables and graphs of growth expectancy of Green and Anderson and others are all inadequate in the face of individual variations. We have not discarded these approximations; they furnish valuable help in planning stapling operations. When the staples are in, however, further decisions are

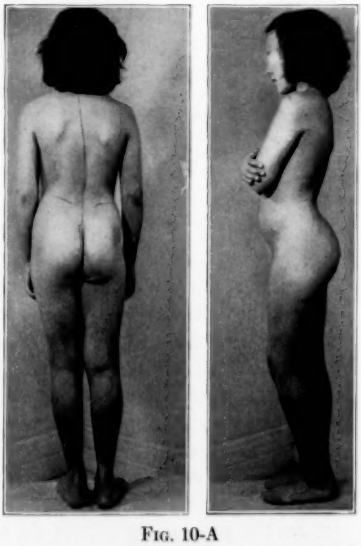

FIG. 10-A

C. P., aged nine. February 4, 1948. This child had had monarticular atrophic arthritis of the left knee at the age of two years. The active process subsided, leaving flexion deformity of 25 degrees of the left knee and overgrowth of the left femur.

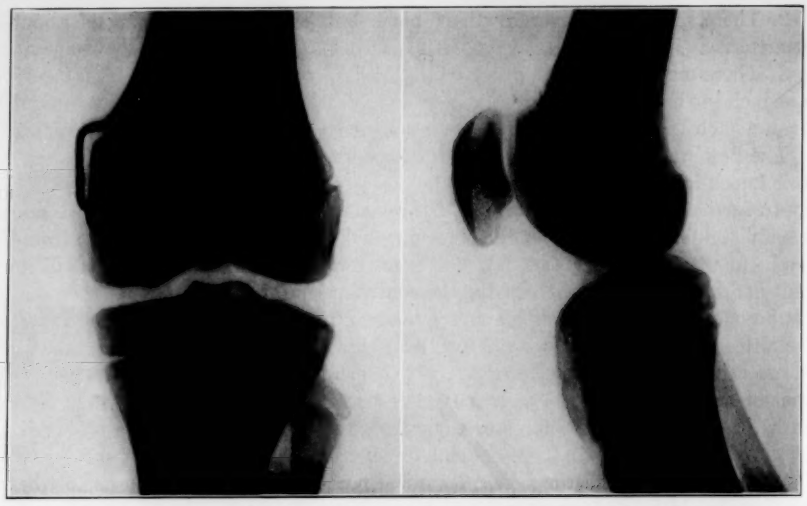

FIG. 10-B

Fig. 10-B: June 11, 1948. Four months after stapling to correct both linear and angular deformities.

Fig. 10-C: Diagram of staples placed to correct overgrowth and flexion deformity simultaneously.

Fig. 10-D: January 5, 1949. Staples were left in place ten months. Photographs, taken one month after removal, show that left knee is straight and pelvis is level.

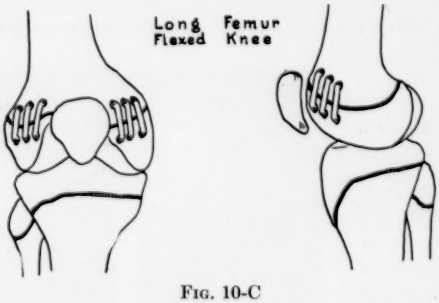

FIG. 10-C

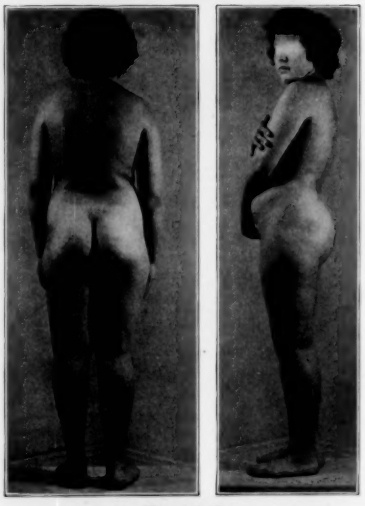

FIG. 10-D

based upon clinical observation and not upon calculation. Actually, only two precautions are necessary to ensure successful timing: (1) The staples must be inserted early enough (but not usually before eight years) to assure correction before growth is completed. (2) The patient must be observed frequently, so that the staples may be removed at just the right time.

The indication for removal of staples is not determined by measurement, but by watching the patient walk. This is particularly true when an unstable hip, stiff knee, drop-foot, or other abnormality influences the decision. It is helpful to have the patient remove the shoe on the side of the longer extremity, so that the effect of further shortening may be observed. In the presence of multiple deformities, the removal of staples becomes the "micro-adjustment" of disability correction. With increased experience, we frequently operate for discrepancies of length that are less than the average error in prediction by the actuarial method.

We do not know how long one may safely leave staples *in situ* with the assurance of growth after removal. In 1945, Phemister[10] suggested that the interval be limited to two years. In adhering to this rule, we have encountered no untoward epiphyseal closures. It is probable that a longer interval is safe in most cases. Further studies will be made with reference to this important point.

CONCLUSIONS

1. Efficient stapling of the distal femoral and proximal tibial epiphyses stops the elongation of bone at these epiphyses immediately and almost completely.

2. The operation is less extensive and the risk of complication is less than with other operative methods of controlling bone growth.

3. Angular deformity may be corrected during the growth period. Knock-knee, bow-leg, back-knee, flexion deformity, or combinations of these deformities are rapidly overcome.

4. The occasional complicating irregularities of growth following stapling should be detected clinically and corrected immediately by rearrangement of the staples.

5. After removal of the staples, growth at the epiphysis is resumed at about the same rate as would be expected on the other side, if both sides were normal. It is sometimes faster and sometimes slower. The variations in rate are usually caused by factors other than staples.

6. The best proof of the normal rate of growth after removal of staples is the persistence of a straight extremity after correction of an idiopathic knock-knee.

7. Several important questions are being studied further:

A. What is the ideal size and design of staples?

B. For what length of time and for what ages is it safe to leave staples in place?

C. What are the factors influencing epiphyseal closure?

D. What is the rate of growth after removal of staples which were inserted for various conditions?

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PREDICTION OF UNEQUAL GROWTH OF THE LOWER EXTREMITIES IN ANTERIOR POLIOMYELITIS *†

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One of the more important deformities caused by poliomyelitis is unequal growth of the lower extremities. Operations such as epiphyseal fusion, limb lengthening, and limb shortening have been designed for controlling or correcting this unequal growth. In conjunction with these operations, normal growth in the epiphyses has been studied, so that epiphyseal growth can be predicted with considerable accuracy. No methods, however, have been available for ascertaining in poliomyelitis the expected amount of inequality of growth. In this study, we have attempted to evolve a method of predicting the amount of inequality in the length of the lower extremities that might be expected in a case of poliomyelitis. The records of 820 cases from the Infantile Paralysis Clinic at Massachusetts General Hospital have been reviewed. An intensive study has been made of those patients in whom the disease developed in childhood and who have now reached adult stature.

Comparison was made between the amount of growth of the lower extremities and factors that might affect growth, such as age at onset, relative muscle power of the two extremities, operations, deformities, braces, and skin temperature. It was apparent that two major variables were related to inequality of growth. The first of these was the age at onset of poliomyelitis, and the second, the amount of paralysis in the two extremities. Deformities, braces, variations in skin temperature, stabilization operations, and tendon transplants had no predictable effect on growth in the extremities.

No inequality in length of the extremities can ensue if poliomyelitis occurs after the epiphyses have closed. The time of epiphyseal closure is so inconstant that this study was limited to those patients in whom the onset was before the age of eleven and who have now reached adult stature.

To ascertain the effect on growth of the second major variable, paralysis, several groups of cases were studied. The first group included sixty-four adults who had had poliomyelitis before the age of eleven, each of whom had one normal lower extremity and one involved extremity.

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The amount of muscle involvement in the lower extremities was determined by rating the following twenty-three muscles or muscle groups:

Glutaeus maximus	Gastrocnemius
Iliopsoas	Soleus
Sartorius	Tibialis anterior
Tensor fasciae latae	Extensor proprius hallucis
Hip abductors	Extensor digitorum longus
Hip adductors	Peronaeus tertius
Hip inward rotators	Peronaeus longus
Hip outward rotators	Peronaeus brevis
Quadriceps	Tibialis posterior
Inner hamstrings	Flexor hallucis longus
Outer hamstrings	Flexor hallucis brevis
Flexor digitorum longus	

They were rated by the Lovett method [1], in which an individual muscle is graded as normal, good, fair, poor, trace, or zero. In our study, these gradings were converted to the numerical ratings of 5, 4, 3, 2, 1, and 0, respectively. The total muscle-power score for an extremity was found by adding the numerical ratings for the twenty-three muscles in each extremity. If all the twenty-three muscles in an extremity were normal or 5, the score would be 115; if all were rated fair or 3, the total score would be 69. It is obvious we cannot prove that any patient who has had poliomyelitis has a normal extremity, but for purposes of this paper we define "normal extremity" as one with muscle power of 111 to 115, and assume that extremities having this score have had normal growth. We consider an "involved extremity" to be one with a muscle score lower than 111. Only Lovett examinations done two years or more after the onset of poliomyelitis, when the muscle pattern was stable, were used.

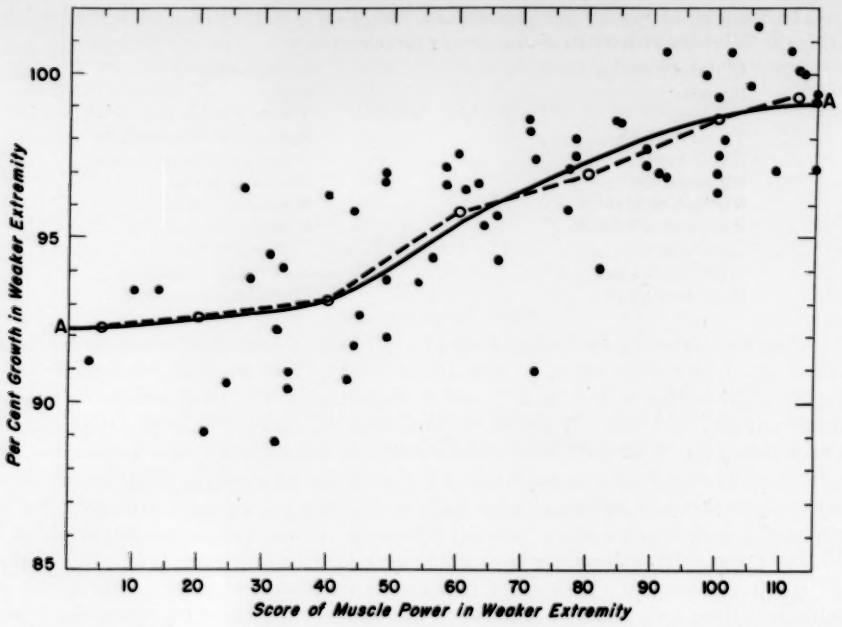
It might seem more logical for a large muscle to be given a greater numerical rating than a small muscle. The assigning of a value of 5 for a normal quadriceps and of the same value for a normal peronaeus muscle is possibly open to criticism. However, muscles measured by weight or volume vary greatly from childhood to adult life and from person to person. It seemed unnecessarily complicated to use a weighted factor for muscles of various sizes. The results later showed that this modified Lovett method of evaluating the power of an extremity, without reference to the size of the individual muscles, was satisfactory for our purposes.

As a check on this method of scoring the muscle power of an extremity, a series of tests were done to determine in another way the comparative strength of the normal and of the involved extremities. A spring balance was used to measure the strength of the muscle groups controlling flexion, extension, abduction, and adduction at the hip, and flexion and extension at the knee and the ankle. The total power of one extremity was compared with that of the other. Similar ratios of relative muscle strength were obtained by the two methods.

Length of the lower extremity was determined by clinical measurement from the anterior superior iliac spine to the tip of the medial malleolus. In most of the cases, this measurement was verified by scanograms or teleoroentgenograms.

In the analysis presented here, the relative length of the two extremities was expressed as "percentage of growth in the weaker extremity". This percentage was obtained by dividing the length of the weaker or involved extremity by the length of the stronger or normal extremity.

Graph I shows the relationship of the growth of the involved extremity to its muscle power. The abscissa records the muscle-power ratings of the involved or weaker extremity, and the ordinate records the percentage of growth of the involved extremity. One hundred per cent. represents equal growth of the normal and involved extremities; 88 per cent. means that the involved extremity is 12 per cent. shorter than the normal one. Each solid dot on the graph represents one case. The average and trend lines for these dots have



GRAPH I

This graph presents sixty-four adults who had acute poliomyelitis before the age of eleven and were left with one normal extremity and one involved extremity. Each solid dot represents one case and is so placed that it records the muscle power and percentage of growth in the weaker extremity. The score of the muscle power in the weaker extremity is recorded on the abscissa; the percentage of growth in the weaker extremity is recorded on the ordinate. (Percentage of growth in the weaker extremity was found by dividing the length of the weaker extremity by the length of the stronger extremity.) The broken line with the circles shows the average relationship between percentage of growth and muscle power. Line *A* is the trend line for the entire series of data.

been drawn. The small circles connected by the broken line represent average values. Beginning at the left and proceeding to the right, the first circle represents the average percentage of growth of the cases with a muscle-power score between 0 and 10; the next circle is the average for cases with muscle power from 11 to 30, inclusive; each of the successive circles represents the averages for groups of cases with muscle power between 31 and 50; 51 and 70; 71 and 90; 91 and 110; and 111 and 115. With the average line as a guide, a trend line, *A*, was constructed.

The age at onset of poliomyelitis in these sixty-four cases varied from two months to ten years. In sixteen cases (25 per cent.), the onset of poliomyelitis was in the first and second years of life; in twenty-four cases (38 per cent.), the onset was in the third and fourth years; in thirteen (20 per cent.), in the fifth and sixth years; in seven (11 per cent.), in the seventh and eighth years; and in four (6 per cent.), in the ninth, tenth, and eleventh years.

The relationship of the age at onset to inequality of limb length was considered. The premise that the earlier the onset of poliomyelitis, the greater would be the shortening, was not proved in this group of cases. If the age at onset had affected growth, those with an early onset would have had greater than the average amount of shortening and would have been below the trend line in Graph I. The average age at onset of the cases below the trend line was 3.2 years; for those above the trend line, it was practically identical, or 3.1 years.

The cases were analyzed further, to ascertain the effect of the age at onset, by divid-

TABLE I

CASES WITH MUSCLE SCORE UNDER FIFTY-EIGHT IN INVOLVED EXTREMITY

	Age at Onset	
	0–5 years	6–10 years
Number of cases	21	3
Average muscle score	37	19
Average percentage of growth	93.1	92.4

TABLE II

CASES WITH MUSCLE SCORE BETWEEN 58 AND 115 IN INVOLVED EXTREMITY

	Age at Onset	
	0–5 years	6–10 years
Number of cases	32	8
Average muscle score	85	97
Average percentage of growth	97.8	97.3

ing them into two groups, according to the muscle score in the involved extremity; each of these groups was subdivided according to age at onset. In cases where the muscle power was less than 58 (Table I) and the onset under the age of six, the average percentage of growth was 93.1. When the onset was from six to ten years, inclusive, the average percentage of growth was 92.4. These groups represent only twenty-one cases and three cases, respectively, so that the figures are not conclusive; but at least for these twenty-four cases, the patients in the groups with onset from six to ten years, inclusive, had essentially the same amount of shortening or slightly more shortening than those with an earlier onset.

Another analysis (Table II) was made for cases with moderate to no weakness, or a muscle score between 58 and 115 in the involved extremity. In this group, there was no significant difference between the percentage of growth in cases with early or late onset. For the entire group of sixty-four cases, the average percentage of growth was identical in the younger and the older patients (Table III).

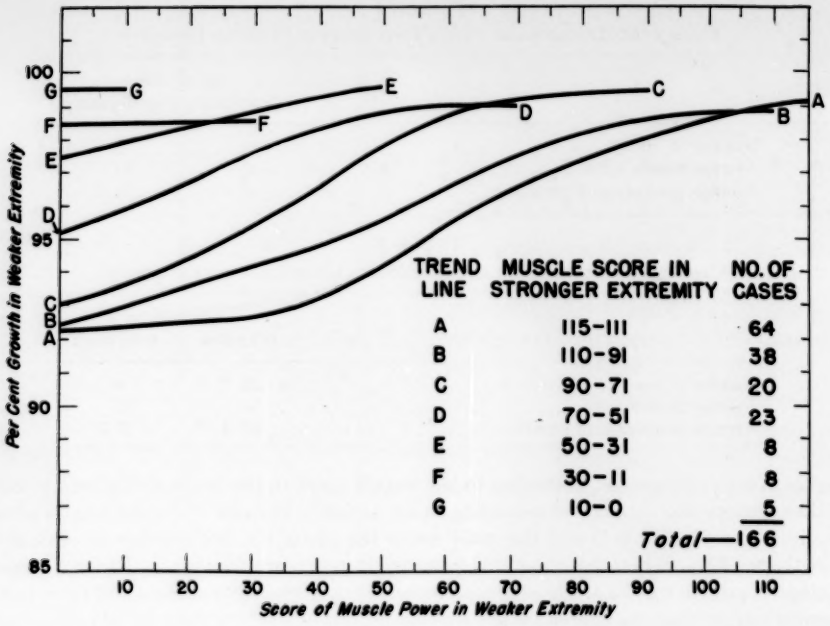
TABLE III

CASES WITH MUSCLE SCORE BETWEEN 0 AND 115 IN INVOLVED EXTREMITY

	Age at Onset	
	0–5 years	6–10 years
Number of cases	53	11
Average muscle score	66	76
Average percentage of growth	95.9	95.9

After studying the patients who had one normal extremity and one involved extremity, those with bilateral involvement were analyzed. In order to do this, they were divided into groups as follows: The data on thirty-eight patients having a muscle-power score of 110 to 91 in one extremity and the same or a lower score in the other were plotted and a trend line was constructed (Graph II,*B*). This shows the percentage of growth attained in the weaker extremity with varying muscle-power scores. Similarly, the data for twenty patients who had a muscle score of 90 to 71 in one extremity and the same or a lower score in the other extremity were plotted (Graph II,*C*). Similar trend lines for the other groups were made, as shown in Graph II.

To use these data clinically in the prediction of inequality of limb length, the percentage of growth shown on the charts must be transposed into centimeters of shortening. In the first group of cases analyzed, the average length of the normal extremity was 86.4



GRAPH II

This graph presents 166 adults who had poliomyelitis before the age of eleven; they have varying amounts of residual muscle power in the lower extremities. Trend line *A* is for patients who had a muscle score in the stronger or normal extremity of 115 to 111 and a score in the other extremity of 0 to 115. Trend line *B* is for patients who had a muscle power of 110 to 91 in one extremity and the same or a lower score in the other extremity. It shows the percentage of growth attained in the weaker extremity with varying muscle-power scores. Patients who had a muscle score of 90 to 71 in one extremity and the same or a lower score in the other extremity are represented by line *C*. Other groups are shown as indicated.

centimeters (34 inches). If this average length is multiplied by the percentage of growth, the product is the length of the involved extremity. By subtracting the calculated length of the involved extremity from the length of the average normal extremity, the amount of shortening is obtained (Table IV). Also included in Table IV is the estimated shortening for an extremity 76.2 centimeters long and for an extremity 96.5 centimeters long (four inches shorter and four inches longer than the average length). If the percentage of growth is 99, the shortening in the short, average, and long extremities would be 0.8, 0.9 and 1.0 centimeters, respectively. The variation of these amounts from the shortening in the extremity of average length is as small as or smaller than the margin of error in clinical measurements. With 94 per cent. growth, the shortening of the short, average, and long extremities would be 4.6, 5.2, and 5.8 centimeters. Again the variation from the extremity of average length is small (0.6 centimeters), and is of the same order or smaller than the

TABLE IV

ESTIMATED SHORTENING IN EXTREMITIES OF VARIOUS LENGTHS

Length of Extremity	Percentage of Growth		
	99	94	88
Short (76.2 centimeters or 30 inches)	0.8 cm.	4.6 cm.	9.1 cm.
Average (86.4 centimeters or 34 inches)	0.9 cm.	5.2 cm.	10.4 cm.
Long (96.5 centimeters or 38 inches)	1.0 cm.	5.8 cm.	11.6 cm.

TABLE V

SIXTY-FOUR PATIENTS WITH ONE NORMAL LOWER EXTREMITY
(MUSCLE SCORE OF 115 TO 111)

Muscle Power in Weaker Extremity	Amount of Shortening in Weaker Extremity (*Centimeters*)
115–111	0.8
110–91	1.2
90–71	2.3
70–51	4.0
50–31	5.8
30–11	6.4
10–0	6.7
One standard deviation	±1.5

variation in clinical measurements. When the percentage of growth is 88, the variation of shortening is somewhat larger. It is evident that there is usually insufficient variation of shortening to necessitate making corrections for long and short extremities. Therefore, all later calculations were based on extremities of average length.

By using this method for calculating shortening, the percentage of growth represented by the trend line in Graph I can be converted to centimeters of shortening for an extremity of average length (Table V). The standard deviation for these cases, in terms of shortening, was 1.5 centimeters.

TABLE VI

SHORTENING

OF LOWER EXTREMITIES AFFECTED BY POLIOMYELITIS

MUSCLE POWER LEFT EXTREMITY	MUSCLE POWER RIGHT EXTREMITY						
	115-111	110-91	90-71	70-51	50-31	30-11	10-0
115-111	*CM.* 0.8	*CM.* 1.2	*CM.* 2.3	*CM.* 4.0	*CM.* 5.8	*CM.* 6.4	*CM.* 6.7
110-91	1.2	1.0	1.6	2.9	4.5	5.5	6.3
90-71	2.3	1.6	0.5	1.0	3.0	4.8	5.8
70-51	4.0	2.9	1.0	0.8	1.4	2.9	3.8
50-31	5.8	4.5	3.0	1.4	0.3	1.4	2.0
30-11	6.4	5.5	4.8	2.9	1.4	1.3	1.3
10-0	6.7	6.3	5.8	3.8	2.0	1.3	0.4
	± 1.5 *CM.* ONE STANDARD DEVIATION						

STINCHFIELD, BARR AND REIDY, MASSACHUSETTS GENERAL HOSPITAL, BOSTON, MASS. TENTATIVE, 1948

In a similar fashion, the calculated shortening for an extremity of average length was determined for the other groups of cases shown in Graph II (Table VI). This table represents the statistical analysis of 166 cases of poliomyelitis with onset before the age of eleven. The calculated average shortening occurring with varying amounts of muscle weakness is recorded. The standard deviation for the first column of sixty-four cases having one normal extremity (vertical column 115–111) was 1.5 centimeters. The standard deviation for the other groups of cases did not exceed this amount.

A means was sought for applying this information to the prediction of expected shortening. We had found early in the study that, after the acute stage of poliomyelitis, the muscle power gradually improved for eighteen to twenty-four months. Following this period, there was usually little change in the muscle pattern. It appeared, therefore, that prediction of shortening could be based on muscle examinations done two or more years after the onset of the disease.

Although the prediction of growth or lack of growth is subject to much individual variation, it was anticipated that clinical application could be made of the relationship between muscle power and shortening found in this study. To predict the amount of shortening, a muscle examination done by the Lovett method should have been made two or more years after the onset of the disease. After the muscle gradings of normal, good, fair, poor, trace, and zero have been converted to the numerical gradings of 5, 4, 3, 2, 1, and 0, respectively, these gradings are totaled for the right extremity and for the left extremity. The result will give a muscle-power score for each extremity of between 0 and 115. By examining Table VI under the proper column for scoring of the right and of the left extremity, the amount of expected shortening is found. The standard deviation for this table is 1.5 centimeters. Only in cases of poliomyelitis occurring before the age of eleven should this chart be used, as the cessation of growth occurs at some variable time after this age.

SUMMARY

Of 166 adults in whom poliomyelitis developed before the age of eleven, varying degrees of muscle power and shortening were present in the lower extremities. There was no specific relationship between the age of onset and the amount of discrepancy in limb length. There was, however, a definite relationship between the relative muscle strength in the two extremities and the discrepancy in limb length. These data may be utilized clinically in predicting the amount of shortening that will occur in a patient having poliomyelitis before the age of eleven.

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DISCUSSION

Dr. William T. Green, Boston, Massachusetts: The problem which Dr. Stinchfield, Dr. Reidy, and Dr. Barr have approached we have found to be a most difficult one, and I am sympathetic with their difficulties and the work involved. For certain of their deductions, they have been forced to use groups of patients which were too few in number for statistical deduction. For example, in comparing the growth of the affected and normal sides in those younger and those older at the time of onset, they have only three patients between the ages of six and eleven in the group with extensive paralysis and only eight patients at this age with lesser degrees of paralysis. This will not allow statistical representation that the effect upon growth is the same, whether a patient is affected by poliomyelitis at an earlier or later age under eleven years. These and other weaknesses in certain portions of this paper arise from the character of the material which had to be used and from the nature of the problem. Moreover, this does not detract from the finding that, in their patients under eleven years of age, the shortening at maturity corresponds with the degree of paralysis, or that it was independent of the age at onset.

If one were hazarding a guess as to what would occur, without any information, this would seem most unlikely. This really means that a child who has poliomyelitis at ten years of age has a much greater degree

of growth inhibition during the growing period than does a child who has the disease at two years of age. To carry this further, in 20 per cent. of our cases in girls, no longitudinal growth occurred after the age of thirteen years. This would mean that in the extreme case of a girl in whom the disease developed just before eleven years of age, a phenomenal inhibition of growth—in certain instances amounting to 100 per cent. or more—would have to occur immediately after the onset.

On the surface, it would seem more logical to expect that a constant coefficient of growth inhibition would exist following poliomyelitis,—that is, that the inherent effects of the disease on the extremity would inhibit growth by a certain percentage each year, and that the shortening would be a product of the amount the patient grows and the percentage of inhibition. In fact, however, this constant coefficient has not occurred in their cases or in ours. Furthermore, our cases show to some degree the tendency which the authors have described, although not to the extent that theirs do. In fact, our cases follow much more closely a constant coefficient of growth inhibition each year, specific to the individual case, than they do a fixed amount which is independent of the age at onset.

These tendencies were demonstrated by distributing fifty of our cases in which infantile paralysis had occurred before the patient was ten years of age, and comparing the amount of shortening which occurred at maturity with the shortening that was predicted by two methods. In one instance, the prediction followed the method of the authors in which the duration of the disease was ignored. In the other, the distribution considered the amount of paralysis and the years of growth remaining after onset. In reality, the latter method represents a prediction based upon an assumed constant percentage of inhibition of growth each year after onset until growth is completed. The prediction was very much better by the second method, although in thirteen of the fifty cases the prediction varied from the real shortening by 1.5 centimeters or more. However, even those outside of the range were quite close to the 1.5 centimeters of variation. By the method proposed by the authors, twenty-two of the fifty missed the prediction by more than 1.5 centimeters, and marked deviation from the prediction existed in many of these. One may conclude that neither method is very dependable.

One of the chief reasons for this, I believe, is that growth is affected to a variable degree by the disease, depending upon the duration after onset. This is illustrated by a survey of our cases. Two hundred and fifty-seven cases in which one lower extremity was affected by variable degrees of paralysis and the other was normal were analyzed as to the annual increments of inhibited growth. These were subdivided into four divisions, based upon the degree of power in residual muscles. In all of the groups, it was found that the average maximum inhibition occurred from the second to the fifth year after the onset of the disease,—that is, there was less inhibition prior to the second year and less inhibition each year after the fifth year following onset.

To carry this point further, seventeen patients who had six years to grow at the time of onset of the disease were studied as to the discrepancy which occurred each year. These patients had unilateral involvement of the lower extremities; the residual muscle power in the affected extremity was sixty-four. It may be seen (Slide) that these patients had sufficient time to go through their years of maximal yearly inhibition, despite the relatively short period of growth after the disease. These cases, therefore, would tend to demonstrate the phenomenon which the authors have described, but it is only relative. If the patients had a longer period to grow, there would be still more discrepancy. However, the inhibition of growth in other years would not be so much as in the critical period of two to five years after onset. In attempting to predict the amount of discrepancy, there has been a high correlation in our cases with the amount of paralysis, but there is great variation.

There are many factors involved which cannot be discussed. All in all, this is a difficult problem, and we are indebted to the authors for their contribution toward its understanding.

We are very much indebted to Dr. Blount for the presentation of his experience in the use of staples to inhibit growth. In correcting discrepancies, the next best thing to being able to stimulate growth is to be able to stop it for an interval and yet have the possibility of allowing growth to resume. It makes accuracy in prediction of growth less important than in ordinary epiphyseal arrest, although no procedure should be carried out without full consideration of the growth which is normally expected from the particular epiphysis and the anticipated effect of the procedure upon growth. Prediction tables should be consulted freely.

From the evidence, this seems to be a very good method to correct certain deformities, if used properly. It cannot be decided at this time whether it is less good or better than the Phemister type of arrest, if one wants to stop growth completely. Certainly the author has had difficulties, as witness the increasing number of staples which he is using now, the broken staples, and the multiple procedures. However, this is inherent in the development of a new method and does not necessarily condemn it. The important thing is that it gives the possibility of having growth resume. Longer observation of more cases will be necessary before we can determine how dependably growth will resume after removal of the staples.

Certainly one must consider carefully, before using staples in younger children, when it is proposed to remove them and have growth resume. Disturbing consequences may result if growth does not start again. Those of us who use this technique must observe our cases carefully, and contribute to an evaluation of the method. We will await with interest Dr. Blount's further observations. The technique has many possibilities.

DR. J. WARREN WHITE, GREENVILLE, SOUTH CAROLINA: Although both of these papers are on the same general subject, the material is so different that one can hardly discuss them together satisfactorily. The report from Dr. Reidy, Dr. Barr, and their associates two years ago, relative to the danger of using roentgen irradiation in arresting growth, was a valuable contribution; the present paper has added new data to the information already contributed by this group.

One would naturally expect more shortening in the cases with greater involvement, but my opinion is that the amount of shortening depends more upon function than upon the empirical figure derived from the muscle-strength test. Not all muscles are affected alike, and a wide variation in function is possible with this method of muscle-strength evaluation, whereas the empirical figure showing the muscle power for the entire extremity is the same. For instance, if the glutaeus maximus and the quadriceps were paralyzed to a high degree, and the hamstrings and hip flexors were relatively unaffected, the final figure would be the same as if all muscles were mildly affected; yet there would be much more associated disability in the case of the seriously involved glutaeus maximus and the quadriceps.

I feel that the shortening would be due to the dysfunction. However, the evaluation of disability is very difficult, and a definite figure, such as that obtained in testing muscle strength, is much more satisfactory. I hope we can depend upon it.

I have had a good deal of difficulty in understanding this paper. I had to read it several times, and I am sure that the audience has had difficulty, also. The charts are a little hard to follow without study. In our own cases of limb-length discrepancy we have marveled at the regularity with which shortening gradually occurs during the growth period. On that basis we have apparently an increasing series, which shows that we can depend on this annual decrement. We have, however, also seen that as constructive surgery is done, and as the patient can use to better effect the short limb, the decrement tends to become less and our own calculations tend to be somewhat upset. Because of this, in making our calculations, we have leaned toward the conservative side. In most instances there is a little more growth than we anticipated; and, if we had been conservative, the overgrowth in sixteen of our earlier cases might not have occurred. In spite of the figures given in the paper, I am of the opinion that, to predict final shortening, one has to watch a patient for a year or two after the first two years of convalescence, and see what the annual decrement is. From that, the final discrepancy can be figured, as seen on one of the charts in our scientific exhibit.

Therefore, we feel that function, rather than paralysis, is important in the determination of final discrepancies. The very fact that muscle power usually coincides with disability permits the conclusion that it may be a good criterion, if the findings continue to be consistent.

Dr. Blount has made a valuable contribution to our armamentarium and to the procedures which can be done,—in this instance, on the long lower extremity rather than the short one. Time will tell how certain it is. I am still a little skeptical, and will wait a few more years before I use staples, except in cases of genu varum or genu valgum. We have used staples in a few of those cases. It is still early to form a definite conclusion, but I think the method is more likely to be valuable in the conditions mentioned than as a means of effecting complete stoppage. There is one difficulty associated with these staples, and that is, as Dr. Blount believes, you can leave them in for only two years. Leaving them in for longer than that tends to produce definite damage, which I am afraid occurs proximally on the metaphyseal side of the plate. Dr. Blount places the staples blindly, and yet doesn't want to have any tissue impaled. This seems contradictory; as one moves the tissue overlying bone, the plate is necessarily exposed and the staples can be placed visually. I think it is important to place the staples visually. The procedure must be very exact; even from the roentgenograms one cannot tell definitely just where the staples are. We are all wondering about the ability of the plate to resume function after it has been stapled for a couple of years. Tremendous force is exerted by these growing cells, and it is surprising that even three staples are strong enough. We shall look forward to a subsequent report on this method of arresting growth.

DR. JOSEPH S. BARR, BOSTON, MASSACHUSETTS (closing): Everyone who has had to deal with the problems of poliomyelitis in the late stage has felt the need for some method of predicting the amount of discrepancy in limb length which could be expected when the patient reached adult life. Up to the present time there has been no method available. The one which we propose has obvious defects and cannot be expected to be accurate in all cases. It should be regarded as a first attempt. We will all look forward to the development of more accurate methods. Nevertheless, this method has the virtue of simplicity. All that is necessary is an accurate muscle examination, done in the late stage of the disease, in a child who has not reached the age of ten or eleven. It requires about five minutes to assign a numerical value to the muscle power in each extremity, to consult the prediction table, and to obtain a figure which in 70 per cent. of our cases has been accurate within an error of less than 1.5 centimeters.

Since our paper was prepared, we have had the opportunity to check the accuracy of the table in ninety-seven additional cases. In seventy-one (or 73 per cent.) of the cases, the actual discrepancy in limb length fell within the predicted range. Twenty-seven per cent. were outside the predicted range.

We realize that relative muscle power in the two extremities is by no means the only factor involved, but it is certainly a major one. At the present time no means are available by which we can measure, in

(Continued on page 500)

EFFECT OF DIATHERMY (SHORT WAVE AND MICROWAVE) ON BONE GROWTH IN THE ALBINO RAT *†

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Physical agents capable of affecting bone growth are of interest to the clinician dealing with growth in general, as well as to the orthopaedic surgeon investigating mechanisms of epiphyseal arrest. The susceptibility of the growing epiphysis to roentgen radiation, demonstrated by recent workers [1, 6], raises the question of a similar effect of high-frequency electrical currents. The widespread use of diathermy in medical practice today emphasizes the need for more information concerning its physiological effects, as well as its potential dangers. This paper describes a set of observations concerning the effect of diathermy, applied to the region of the knee joint in the growing albino rat. Single exposures of either condenser field, short wave (8-meter wave length) or microwave (11-centimeter wave length), were employed in approximately fifty animals. The contralateral knee served as a control. Appropriate animals were sacrificed and examined at varying intervals following exposure for changes in bone length, soft-tissue reaction, and in the roentgenographic and microscopic appearance of the treated epiphysis.

METHOD

1. *Short-Wave Diathermy* (8-meter wave length)

Forty 100-gram albino rats were anaesthetized by intraperitoneal nembutal. A small cuff electrode, 2 centimeters in diameter and 1.5 centimeters wide, suitably insulated with cotton wadding, 0.5 centimeter in thickness, was placed over the right knee joint. The animal was held in place on its back over an insulated indifferent pad electrode, 10 by 6

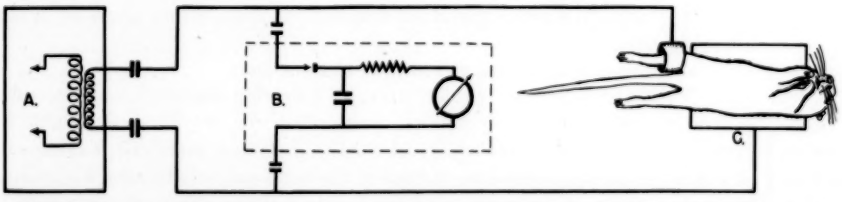

FIG. 1

Method of applying short-wave diathermy to the region of the knee.

centimeters. The electrodes were capacitatively coupled to the spaced plates in the patient's circuit of a standard clinical short-wave diathermy machine. Dosage was regulated by varying the resonance in the patient's circuit. Relative power output in the animal circuit was measured by means of a shielded milliammeter with a fixed shunt resistor, and rectified capacitatively, coupled to the electrode leads (Fig. 1). Meter readings of ten, seven, five, three, and two indicated the relative voltage in the animal circuit in

* Read before the Orthopaedic Section of the American Medical Association, Chicago, Illinois, June 24, 1948.

† This work was aided by a grant from the National Foundation for Infantile Paralysis, Inc.

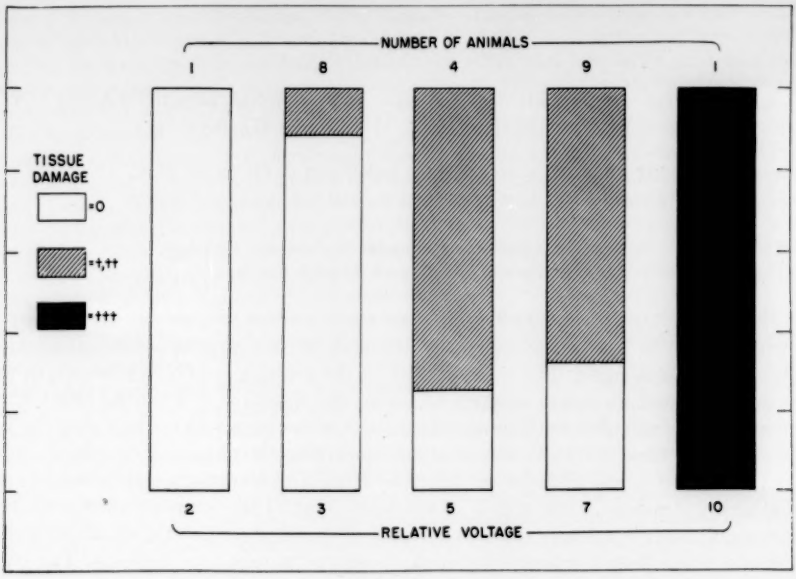

FIG. 2

Relation of short-wave diathermy to soft-tissue reaction.

various experiments. Duration of exposure was either five, ten, or fifteen minutes.

The extremity was examined immediately after treatment and graded according to the following scale, based on soft-tissue reaction:

0: Extremity warm to touch as compared to the control, but no other gross difference noted.

+: Slight swelling present in surrounding soft tissues and slight increase in resistance to passive motion, either alone or in combination.

++: Marked swelling present in surrounding soft tissues and marked increase in resistance to passive motion of the treated joint, either alone or in combination.

+++: Ulceration or evidence of gross tissue destruction.

The animals were observed at regular intervals following exposure; and secondary changes, such as atrophy, limp, or foot drag, were noted. At two, four, six, eight, ten, twelve, and thirty-six weeks after treatment, selected animals were sacrificed. Examination included roentgenograms and gross descriptions of the bone and soft tissues. Microscopic sections were taken of the distal portion of the femur and the proximal portion of the tibia, including the epiphyseal plate in most instances, of both the treated and control limbs.

2. *Microwave Diathermy* (11-centimeter wave length)

Animals under intraperitoneal nembutal anaesthesia were exposed to microwave radiation emitted from a microtherm, a parabolic reflector being used. The animal was placed under a metal shield except for the region of the right knee, thus protecting the rest of the animal from the microwave radiation. In different experiments the source of the radiation was placed at varying distances from the treated limb, ranging from direct contact to 4 centimeters. The power output of the machine was set at either 25 per cent., 50 per cent., or 75 per cent. of the 130-watt total capacity of the instrument. Duration of treatment was ten minutes in all cases, except for one animal which was

TABLE I

SHORT-WAVE DIATHERMY

Rat No.	Voltage	Treatment (*Minutes*)	Clinical Results	Sacrifice (*Weeks after Treatment*)	Condition at Time of Sacrifice	Autopsy and Microscopic Findings
31	10	5	+++	2	Large ulcer, gangrene of foot	
39	7	5	++	2	Limp, ulcer	Purulent arthritis; *Staph. albus*, alpha-hemolytic Strep.; marked degenerative changes
40	7	5	++	4	Limp, ulcer	Thigh atrophy, one-third normal; thickening of joint capsule; limitation of joint motion; marked destruction of epiphysis
37	7	5	+	2	Limp	Muscle atrophy; limitation in joint motion; cystic changes in epiphyseal plate; marrow fibrosis of metaphysis and epiphysis
38	7	5	+	4	Normal	Slight scar over tibia; epiphysis grossly abnormal, narrowed, and partially destroyed
33	7	5	+	4	Normal	Slight scar; ? microscopic changes in epiphyseal plate
34	7	5	+	36	Normal	No changes noted
32	7	5	0	2	Normal	No gross changes; ? cystic degeneration of epiphyseal cartilage
36	7	5	0	6	Normal	No changes noted
35	7	5	0	12	Normal	No gross changes
11	5	5	++	10	Scar, limp	Muscle atrophy; epiphysis grossly abnormal, almost obliterated; hyperplasia of synovial membrane
15	5	5	+	6	Limp, ulcer	Scar adherent to fascia below and lateral to knee; quadriceps atrophy; epiphyseal plate ossified and narrow; synovitis
12	5	5	+	36	Limp, scar	Gross deformity: right femur 2.8 cm., control 3.5 cm.; limited extension of right knee
14	5	5	0	36	Normal	No changes noted
13	5	3	+++	2	Ulceration, gangrene of foot	Spontaneous amputation of leg
29	3	15	++		Died 10 days after treatment	Deep ulceration of thigh
26	3	15	+	6	Scar, ? limp	No gross changes; knee cut with diminished resistance; minor changes in epiphyseal cartilage
27	3	15	+	10	Normal	No gross changes
28	3	15	0	36	Normal	No changes noted
30	3	15	0	36	Normal	No gross changes
16	3	5	+	36	Normal	No gross changes
19	3	5	0	3	Normal	No gross changes
18	3	5	0	4	Normal	No gross changes
20	3	5	0	6	Normal	No changes noted
17, 21, 23, 24, 25	3	5	0	36	Normal	No changes noted

TABLE II

MICROWAVE DIATHERMY

Rat No.	Relative Wattage *	Treatment (*Minutes*)	Distance from Reflector (*Centimeters*)	Clinical Result	Sacrifice (*Weeks after Treatment*)	Condition at Time of Sacrifice	Autopsy, Microscopic, and X-Ray Findings
41	75	10	Contact	Animal did not survive			
42	25	10	Contact	+++	34	Flail extremity	Complete absorption of lower portion of femur and upper portion of tibia, with skin pedicle connecting foot to trunk (see text and Figs. 9-A and 9-B). Cross section of pedicle shows nerve and skin normal; muscle bundle atrophied; no evidence of bone.
43	25	10	1	++	4	Scar, limp	Muscle atrophy; increased periarticular yellow fibrous tissue; marked synovial hyperplasia. Complete absence of epiphyseal cartilage in distal portion of femur.
44	25	10	2	+	8	Muscle atrophy; no scar; slight limp	Right tibia 31 m.m., left tibia 34 m.m. Right femur 24 m.m.; left femur 29 m.m. (control). Destruction of central portion of femoral and tibial epiphyseal cartilage.
45	50	10	1	++	2	Limp, ulceration	Muscle atrophy; no gross bone changes. One end of epiphysis destroyed, but epiphyseal plate not injured.
46	25	40	4	0	Died †		
47	50	10	4	0	34	Normal	No changes noted
48	75	10	4	0	34	Normal	No changes noted
49	25	10	2	0	2	Normal	No changes noted
50	25	10	1.5	0	34	Normal	No changes noted

* Percentage of 130-watt total output.

† This animal died, of unknown cause, five weeks after treatment.

exposed at low intensity for forty minutes. Following the treatment, the animals were graded as to soft-tissue reactions and examined as described.

RESULTS

The results (Tables I and II) can be summarized under the following headings: (1) relation of diathermy dosage to soft-tissue reaction; (2) relation of diathermy to bone growth; and (3) pathological changes in bone and soft tissues following exposure to diathermy.

1. *Relation of Diathermy Dosage to Soft-Tissue Reaction*

In these experiments the relative voltage employed in the exposure is compared with the resulting soft-tissue reactions. The results of short-wave diathermy are shown in Figure 2.

Although there is a general correlation between the relative dose and the degree of tissue injury, sufficient variation in response exists to make accurate and predictable dosage impossible under the existing conditions. It is well known that variation in the distribution of the electric field will result from minor differences in the geometric orientation between the dielectric and the electrodes[3]. It is conceivable, therefore, that, despite the same relative voltage readings between the electrodes in different experiments, minor variations in the application of the cuff electrode or conformation of the extremity would alter the distribution of the electric field sufficiently to account for the differences in tissue reaction.

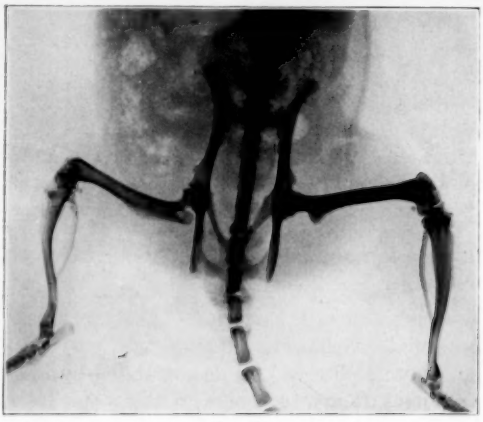

FIG. 3

Roentgenogram of rat (No. 12), thirty-six weeks after short-wave diathermy to right knee (five-minute treatment at relative voltage of five), showing obliteration of joint space, atrophy of epiphysis, and shortening of femur (2.8 centimeters; control 3.5 centimeters). Note also shortening of tibia, atrophy of fibula, and narrowing of tibial epiphyseal plate.

With microwave radiation, similar difficulties arise in the accurate measurement of dosage. In general, the dose can be varied by changing the power output of the machine, the distance of the extremity from the source of radiation, and the duration of the exposure. In the experiments described, the dose was varied in such a manner as to produce all grades of tissue reaction from mild warmth to the touch, with no objective changes (Grade 0), to marked evidence of tissue destruction (Grade +++). As would be expected, there was more marked tissue reaction with higher power output and shorter distances from the source of emission. Because the field strength of the microwaves diminishes as the square of the distance from the source, and since the distances used in the experiments were comparatively small, exact dosage was not possible. The field distribution of the microwaves is unidirectional.

In view of the difficulties in quantitatively estimating precise dosage and distribution of energy in any individual experiment, it was considered more reliable to correlate bone-growth disturbance with the soft-tissue response immediately after exposure to diathermy.

2. *Relation of Diathermy to Bone Growth*

In animals where no soft-tissue changes—swelling, muscle spasm, ulceration, et cetera—were produced following diathermy treatment, no subsequent changes were observed in bone growth, either grossly or by microscopic examination. In nineteen animals

TABLE III

RELATION OF SOFT-TISSUE CHANGES FOLLOWING SINGLE EXPOSURE TO SHORT WAVE OR MICROWAVE AND SUBSEQUENT EFFECT ON BONE GROWTH

Grade of Soft-Tissue Reaction	Number of Animals	
	No Effect on Bone Growth	Disturbance of Bone Growth
0	19	—
+ or ++	6	9
+++	—	3

graded 0 following a single exposure to either short-wave or microwave diathermy, the treated extremity continued to grow normally, as evidenced by roentgenograms, measurement of the femur at autopsy, and microscopic examination of the epiphysis. Five animals with mild swelling and muscle spasm (Grade +) and one animal with marked soft-tissue swelling (Grade ++) also showed normal growth. The remaining twelve animals with disturbance in bone growth had soft-tissue changes (Table III).

3. *Pathological Changes in Bone and Soft Tissue Following Diathermy*

As stated, pathological changes in the bone were found only in those animals receiving sufficiently large doses of diathermy to cause soft-tissue injury. In these cases, immediately following the treatment, varying degrees of soft-tissue swelling and muscle spasm were observed, as demonstrated by increased resistance to passive motion of the knee joint. In more severe cases, this was followed within twenty-four to forty-eight hours by ulceration and necrosis of the skin and soft tissues. Healing was slow and varied with the extent of the burn. In a few of the most severe cases, gangrene was followed by spontaneous amputation of the leg.

The subsequent disturbances in bone growth following exposure to short-wave diathermy did not always parallel the degree of soft-tissue change. In several animals (Nos. 16, 34, and 35), moderate soft-tissue changes following treatment failed to be accompanied by subsequent disturbance in bone growth, as evidenced by roentgenographic or microscopic study of the epiphysis. In another group, however, with comparable immediate soft-tissue changes following treatment (Nos. 12, 15, 37, and 38), considerable impairment in bone growth became apparent in later roentgenographic and pathological studies (Fig. 3). In general, the roentgenographic findings paralleled the gross and microscopic changes.

Many of the pathological changes observed microscopically were not unlike the changes observed after epiphyseal irradiation by Gall, Lingley, and Hilcken. (An excellent description of the normal histology of the epiphysis of the albino rat may be found in their paper.) The earliest changes consisted in swelling of the cartilage cells of the epiphyseal plate with fibrillation of the matrix, followed by cyst formation in a few of the cases (Figs. 4 and 5). The epiphyseal plate became narrow, irregular, and distorted; and in some animals there was complete destruction of a portion of it. In the cases with severe damage, the epiphysis itself was shrunken and distorted, and the marrow was fibrotic (Fig. 6). In a few cases the articular cartilage showed degeneration and there was hyperplasia of the synovial membrane. The hyperplasia was more marked in the animals treated with microwave diathermy.

In the microwave experiments, no disturbance in bone growth was observed in any animal which did not show obvious soft-tissue change immediately after treatment. Of the ten animals used, one died immediately because the dose was too large; five apparently received too small dosage to produce any clinical or anatomical change; one (No. 45) showed

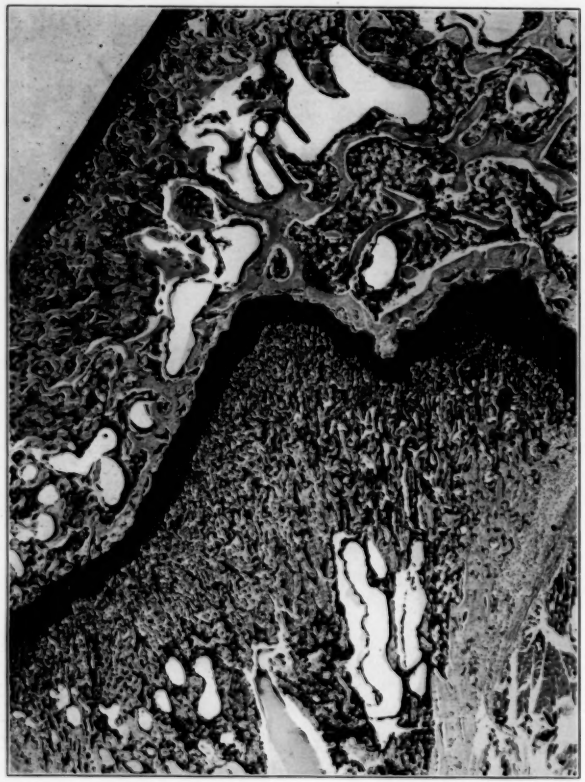

FIG. 4

FIG. 5

Fig. 4: Photomicrograph (× 30) of lower end of femur of a rat with normal epiphysis, epiphyseal plate, and diaphysis.
Fig. 5: Photomicrograph (× 30) of lower end of femur of a rat (No. 37), two weeks after short-wave diathermy, showing cystic changes in the epiphyseal plate and marrow fibrosis of epiphysis and metaphysis. (Compare with Fig. 4.)

destruction of one side of the epiphysis and articular cartilage, but the epiphyseal plate was not injured. In another animal (No. 44), following exposure to microwaves, a moderate degree of local swelling appeared, which persisted for several days without obvious ulceration of the skin. In spite of this mild soft-tissue reaction, there were definite bone changes, resulting in shortening of the femur during subsequent growth (Figs. 7-A and 7-B). Microscopic examination in this animal showed destruction of the central portion of both femoral and tibial epiphyseal plates, as well as a portion of the femoral epiphysis and articular cartilage (Fig. 7-C). Similar changes were seen in still another animal (No. 43). An additional finding here was the extensive synovial hyperplasia, almost neoplastic in appearance (Fig. 8).

The one animal (No. 42) that survived a large microwave dose and was sacrificed at thirty-four weeks showed a bizarre result. Immediately after exposure to microwave there was considerable swelling, followed in forty-eight hours by ulceration of the superficial tissues. Healing was slow and was followed by complete absorption of the distal portion of the femur and the proximal portion of the tibia (Figs. 9-A and 9-B). The resulting flail foot was connected to the trunk by a pedicle of skin and connective tissues. The circulation, bone structure, and sensation to pin prick, as evidenced by the animal's response, were apparently unimpaired in the flail foot.* A cross section of the pedicle (Fig. 9-C) shows complete absence of the bone. The skin surface on one side is normal, still containing the skin appendages, while that on the other side has apparently regenerated following the ulceration. All the muscles are atrophic and the nerves are still present.

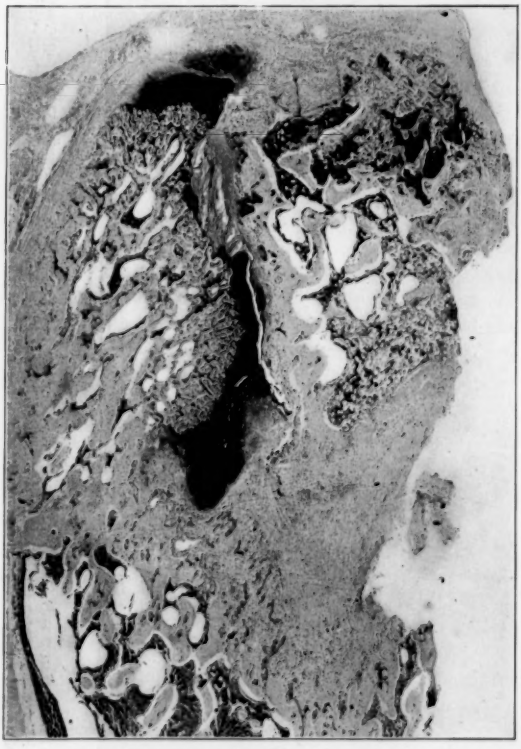

FIG. 6

Photomicrograph (× 30) of lower end of femur of a rat (No. 38), four weeks after short-wave diathermy, showing marked distortion and fibrillar degeneration of the epiphyseal plate, marrow fibrosis, contraction of epiphysis, and degeneration of the articular cartilage.

DISCUSSION

A review of the literature provides very little information concerning the effect of diathermy on bone growth. In 1932, Nové-Josserand reported deformity of the calcaneus and epiphyseal arrest of the distal portion of the tibia in an eight-year-old girl, who, when she was only five months of age, had had a diathermy burn in the region of the heel. This was accompanied by 6 centimeters of shortening. Nové-Josserand stated that the calcaneal lesion, which corresponded to the cutaneous scar, resembled that which one would see in any deep burn of the heel of a child. What was remarkable was that the bony lesion also produced an important effect on

* Similar deformities were produced with microwave radiation in another group of experiments; details of the pathogenesis will be reported later.

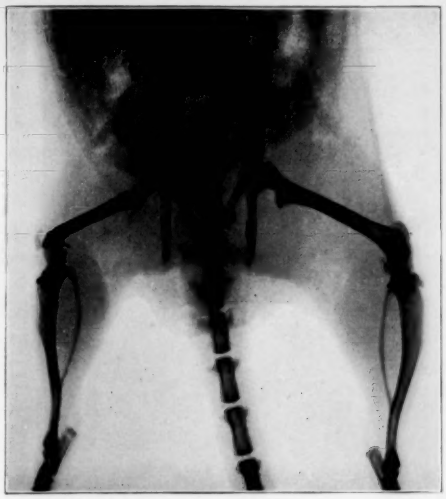

FIG. 7-A

FIG. 7-B

Fig. 7-A: Roentgenogram of rat (No. 44), eight weeks after microwave diathermy, showing destruction of femoral and tibial epiphyses and atrophy of patella. Note shortening of femur (2.4 centimeters as compared with the control measurement of 2.9 centimeters) and tibia (3.1 centimeters as compared with the control measurement of 3.4 centimeters). The tibial epiphyseal plate is narrowed.

Fig. 7-B: Photograph of lower extremities of same rat, showing shortening of bones.

the talus and the lower end of the tibia, whereas the skin at this level remained absolutely intact. Although not mentioned by the author, we can assume that the instrument responsible for the burn was of the conventional long-wave variety (approximately 100-meter wave length), in use before the present era of short-wave machines.

A personal communication * affords another instance of disturbance in bone growth, presumably related to a diathermy burn. A five-month-old South American girl was stricken with poliomyelitis, with marked involvement of both lower extremities. Thirteen days after the onset of the disease, the child was treated with short-wave diathermy. An electrode was placed on the right ankle and another over the back. After twenty-five minutes of treatment she had the symptoms of heat stroke, accompanied by cardiac and respiratory collapse and convulsions. A severe burn developed in the region of the right knee, requiring over two months to heal. Roentgenograms taken from six months to three years later showed destruction of the distal femoral and proximal tibial epiphyses (Fig. 10). This was associated with considerable scar tissue and contractures in the region of the knee, which were subsequently removed surgically. The orthopaedic surgeon stated: "From the history of the use of short-wave diathermy, one is forced to the conclusion that the epiphyseal lesion is due to the deep heat induced by the short-wave diathermy apparatus. In my opinion this lesion is not due to any type of disease, and I have never seen the condition in any case of poliomyelitis. This child now has one and one-half inches of shortening due to this lesion and the shortening will progress. . . . One can suspect that there will probably be at least six inches of shortening when the child arrives at adult life."

Aside from the two examples mentioned, no instances have come to the authors' attention in which this serious sequela to diathermy burns has been reported.

In 1934, Weinberg and Ward reported the experimental observation of increased vascularization and bone repair in bone defects in dogs, subjected to daily treatment with conventional diathermy. They reported higher temperatures in the bone than in the

* The authors are indebted to Frank R. Ober, M.D., for permission to publish a report of this patient.

FIG. 7-C

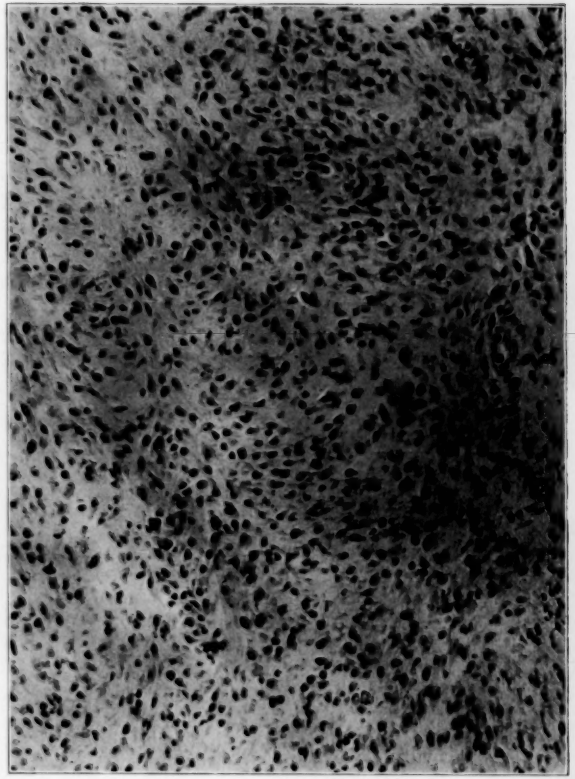

FIG. 8

Fig. 7-C: Photomicrograph (× 30) of lower portion of femur, showing destruction of epiphysis, epiphyseal plate, and articular cartilage.
Fig. 8: Photomicrograph (× 135) of rat No. 43 shows marked synovial hyperplasia, four weeks after microwave diathermy.

surrounding soft tissues during the diathermy treatment. The accuracy of the temperature studies is open to question, since Weinberg and Ward implanted clinical thermometers in the tissues during the experiment.

Osborne and Coulter, on the other hand, studying the thermal effects of short-wave diathermy on bone and muscle in dogs, employed thermocouples placed in hard-rubber cannulae before and immediately after local exposure to various wave lengths and concluded that, although the temperature of the marrow may be increased more than the general body temperature, the temperature of the surrounding muscle was always higher. These authors concluded that the degree of tissue injury must always decrease from the periphery to the interior. This conclusion presupposes the same susceptibility of all types of tissue to thermal injury. It is quite possible, and even probable, that variation in vascular supply and in specific resistance to thermal injury exists in different tissues. The epiphyseal cartilage, for example, may be considerably more liable to permanent damage than the overlying skin and muscle, despite the same degree of temperature elevation.

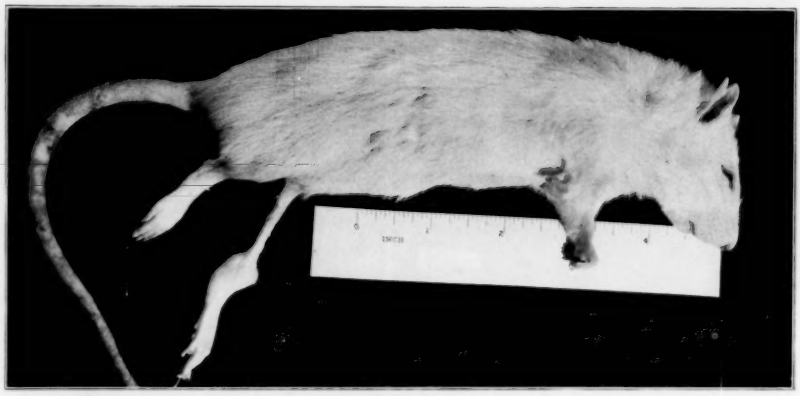

FIG. 9-A

Photograph of rat (No. 42), thirty-four weeks after a large microwave dose. Shows flail foot, resulting from dissolution of the knee and of portions of the femur, tibia, and fibula.

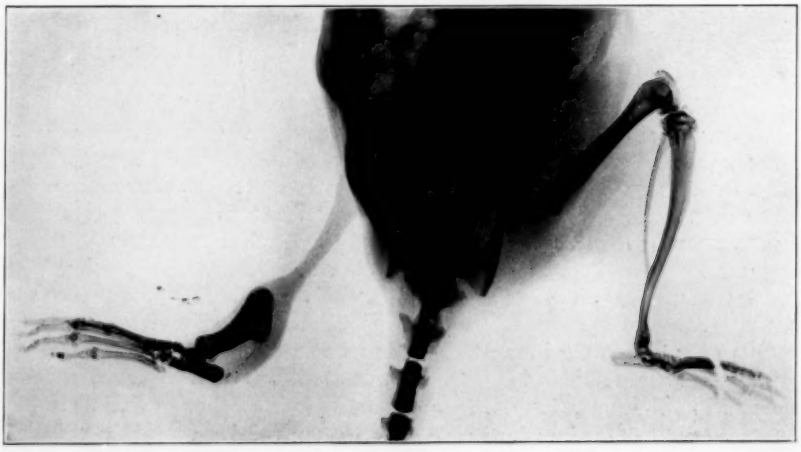

FIG. 9-B

Roentgenogram of same rat shows the absence of bone in the skin tube.

FIG. 9-C

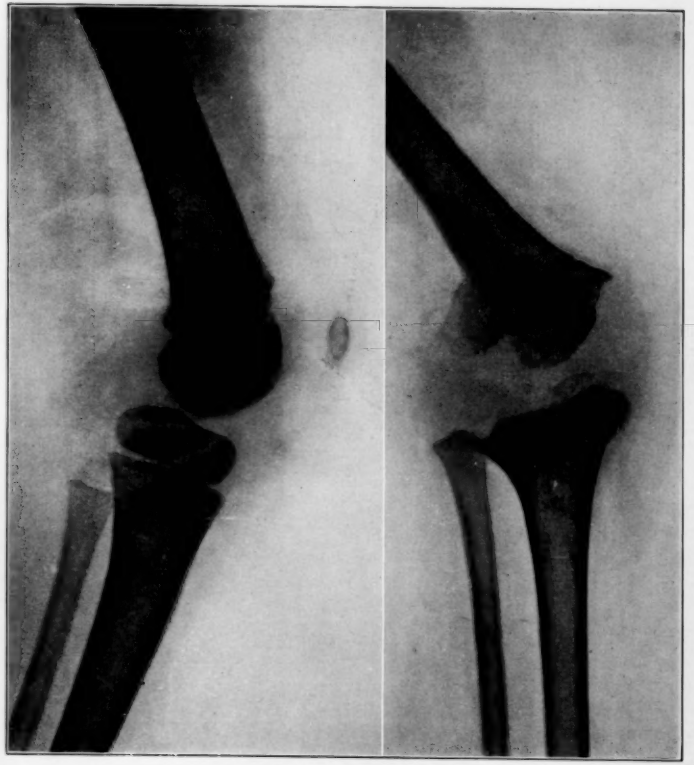

FIG. 10

Fig.9-C: Photomicrograph (× 40) of cross section of skin tube, demonstrating absence of bone and preservation of muscle and nerves. Note absence of skin appendages in corium on side treated, in contrast to their preservation on other side.

Fig. 10: Roentgenograms of knee in an eleven-month-old child, six months after short-wave diathermy, show marked destruction of femoral and tibial epiphyses. There is marked periosteal new-bone formation at the posterior surface of the distal portion of the femur.

To those who have had clinical experience with diathermy, the difficulties of measurement of dosage are apparent. No accurate method is available at present for quantitatively determining the amount and distribution of energy absorbed by the tissues within a high-frequency electric field. In clinical usage, the dosage is varied by altering either the resonance in the patient's circuit or the output of the machine. The therapeutic dosage, however, is determined by the patient's subjective sensation of heat, rather than by any objective measurement of energy absorption. In the experiments reported in this paper, the difficulty in accurate dosage is clearly demonstrated. Despite the controlled conditions employed, it was not possible to predict the exact degree of tissue reaction to a single exposure to short-wave diathermy on the basis of the relative voltage between the two electrodes.

Under the conditions of the experiments, we can find no conclusive evidence that either short wave or microwave, when used in "clinical" dosage, has any appreciable effect on bone growth. In larger doses, however, extensive disturbance in bone growth may ensue. It was further observed that the degree of bone change with short wave, and particularly with microwave, does not always parallel the degree of skin damage or superficial-tissue damage. Perhaps the distribution of the injury following the use of more penetrating heating agents may cause thrombosis of some of the deeper vessels with resulting changes in bone growth, secondary to insufficient vascular supply. Details concerning the pathogenesis of the various lesions await further experimental studies to clarify the distribution of energy in the tissues exposed to the shorter electromagnetic radiation.

Experiments performed on the anaesthetized albino rat must be interpreted very cautiously as to clinical significance. The preliminary findings, however, suggest a warning against the careless or indiscriminate use of diathermy, particularly in the patient who has not attained full growth. The use of electromagnetic radiation as a method of elective epiphyseal arrest in cases of unequal limb length does not appear feasible.

The unusual results following severe microwave burns, characterized by extensive bone absorption, do not exclude the possible therapeutic value of this type of heating when employed in clinical dosage. On the contrary, they suggest greater penetration of these ultra-short electromagnetic waves which, under clinical supervision, may have decided therapeutic advantages. The results merely indicate the necessity for careful control of dosage and the need for further clinical and physiological studies relative to this type of radiation. It is to be hoped that further studies of the biological effects of this portion of the electromagnetic spectrum, as well as technical improvements in instrumentation, will remove some of the hazards existing at present and furnish us with a more effective therapeutic agent.

SUMMARY

1. Single exposures of either condenser field, short wave (8 meters) or microwave (11 centimeters), were applied to the region of the knee joint in approximately fifty albino rats. At varying intervals of time, appropriate animals were sacrificed and examined for changes in bone length, soft-tissue change, and roentgenographic and microscopic appearance of the treated extremity.

2. Soft-tissue injury following large dosages of diathermy showed a general correlation to the applied voltage, but sufficient variation in reaction resulted to make accurate dosage impossible under the conditions of the experiment.

3. When moderate soft-tissue injury was present immediately after exposure to either short-wave or microwave radiation, the subsequent effect on bone growth—shortening, deformity, partial or complete epiphyseal destruction, et cetera—did not always parallel the extent of the soft-tissue injury.

4. An unusual sequela to microwave burn was characterized by extensive bone absorption and resulting flail extremity.

5. In two clinical cases, extensive disturbances in bone growth resulted in children who had received burns following diathermy treatment.

6. Caution should be observed in all diathermy treatments; they may be contraindicated for children.

NOTE: The authors wish to express their sincere appreciation for the generous cooperation received from Joseph S. Barr, M.D., of the Massachusetts General Hospital, Boston, and from Kurt S. Lion, D.Eng., of the Massachusetts Institute of Technology, Cambridge.

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DISCUSSION

UNEQUAL GROWTH OF THE LOWER EXTREMITIES

(*Continued from page 486*)

clinical cases, some of the other factors which might be of great importance, such as relative blood flow and relative function of the two extremities.

DR. WALTER P. BLOUNT (closing): Dr. Green is right in observing that we must be cautious in stapling the epiphyses of young children. Eight years is a good arbitrary figure for the lower age limit, but variations in development will influence the selection of cases. The criteria are approximately the same as those for bone operations on the feet in children. It is mechanically difficult to get the staples to hold in the soft bone and cartilage cap of young children. Occasionally early stapling is desirable. At any age, close observation at frequent intervals is necessary. The younger the child, the more likelihood of extrusion of the staples. This complication should be noted and corrected before angular or linear deformity results.

Dr. White's remarks may have injected two erroneous impressions. Two years is not an absolute limit on the time that staples may be left *in situ*. That is an arbitrary period, established at Dr. Phemister's suggestion when stapling was begun. We are now leaving staples in much longer without untoward results. The safe period will be established only by continued observation, and will be reported at a later date. Certainly three or four years is permissible in most cases.

Dr. White will find, after further experience with the method, that it is almost easier in young children to place the staples blindly than by direct vision. The cartilage cap is so large and the lateral margins of the epiphyseal plate are so expanded that direct vision implies thick flap dissection. The palpable contours are sufficiently accurate to be used as guides, if checked with anteroposterior and lateral roentgenograms. Exposure of the actual epiphyseal plate in young children would lead to damage of the growth center at the time of removal of the staples. In older children, it makes no difference whether the plate is exposed or not.

There is no discrepancy about the impaling of soft parts. Any fascial or aponeurotic layers that move must be divided in the direction of their fibers and retracted. The periosteum and cartilage do not move and may safely be impaled by the staples. Dr. White is right that the insertion must be very accurate. With practice and with biplane roentgenographic control, this is not difficult.

CONSERVATIVE TREATMENT OF FUNCTIONAL DISORDERS OF THE FEET IN THE ADOLESCENT AND ADULT

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The following remarks will be limited to the conservative treatment of complaints of the human foot. Any earnest approach to these matters includes awareness that some feet remain free from common ailments. This emphasizes the presence of intrinsic and extrinsic influences which protect these feet from pain and disability in childhood and adult life. Within the scope of these influences has long been sought the formula for prevention and cure of the common ailments of the human foot.

These efforts are deep in time. Despite the multiplicity of thorough investigations, present-day complaints are the same as those which prevailed in 1819, when right and left shoes were an innovation. It is for these reasons that this subject is again under serious consideration. Awareness of the long background and respect for accumulated observations foster some doubt as to the possibility for the expression of original thought on this subject.

This presentation is based on the succession of events involved in the stance phase of the step. This is assumed to be a logical basis, because the common complaints related to the feet are provoked by and associated with the inherent and environmental conditions which are related to its functional requirements, as expressed in standing and walking. Therefore, a concept of pertinent principles governing foot function takes precedence over the details of therapeutic procedures.

Any fundamental approach to the solution of common complaints of and related to the foot requires consideration of the following points:

1. *Function:* This includes the functional significance of certain osteo-articular relationships; functional limitations of the extrinsic muscles of the foot; and the functional role of the osteo-articular relationships in the control of pronation.

2. *Pronation:* Clinical evidence indicates that strong extrinsic muscles do not assure protection against pronation, but that severe pronation in childhood can be significantly diminished by the effective application of the principles stated in Wolff's law.

3. *Pressure Relationships:* Through recorded pressures on the plantar surface of the foot, a correlation will be established between the location of most frequent complaints and the maximum work done by the foot in walking.

4. *Shoe-to-Foot Relationships:* A study of these relationships shows why the application of principles practised by Hugh Owen Thomas is effective in relieving certain complaints related to the fore part of the foot. Reference will be made to the prevailing disparity between the principles of foot function and the characteristics of the shoes in which they must do their work over a period of many years.

It becomes evident that we are to deal with variables of those clinical problems most frequently seen. The anatomical definitions of function have suggested a simple and direct explanation of the cause and treatment of such common complaints. However, time and an examination of large numbers of these structures deny such assumed regularity. The inherent variables unite to form a structural unit which serves the function of locomotion. The feet have, therefore, in common with other structures, a range of variations within the classification of normal.

When serious attention is directed to the function of the extrinsic muscles of the foot, as necessary for execution of the stance phase of the normal step, we recognize the

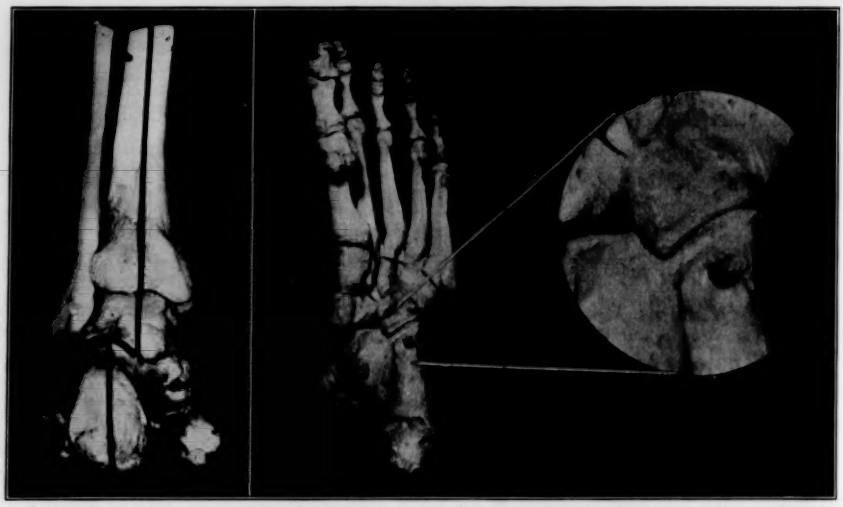

FIG. 1-A FIG. 1-B FIG. 1-C

Fig. 1-A: The axis of weight-bearing through the calcaneus is ±1.5 centimeters lateral to that of the tibia. (Reproduced, by permission, from *The Physiotherapy Review*, **16**: 48, 1936.)

Figs. 1-B and 1-C: The calcaneocuboid lock effectively prevents pronation of the fore part of the foot when the calcaneus is held in alignment with the weight-bearing axis of the tibia.

limitations of definitions from the anatomical laboratories. It is from this single source that concepts of muscle function originated. These views, resulting from dissections of lifeless feet, were presented to explain the cause of and to define the resources available for relief of common ailments of the feet. Although such information was the initial requirement for the full development of gross anatomy, it was only a part of the premise required for the prevention and treatment of clinical problems. It seemed clear, therefore, that the remainder of the premise could not be defined without a method of quantitative analysis by which the functional characteristics of the foot in the stance phase of the step could be revealed.

Thus far, an effort has been made to separate certain theories based on gross anatomy and their limitations when they are applied to those clinical problems of the feet which have been common to successive generations. One of the oldest of these problems is that of pronation. It is difficult to find in the literature evidence to support the claims made for the treatment of this condition, as recommended in current textbooks.

The functional characteristics of the osteo-articular structures involved in pronation should, therefore, be reviewed. In a previous communication [3], the authors called attention to the tibia as a weight-bearing column with the calcaneus serving as its foundation (Fig. 1-A). The axis of weight-bearing of the foundation is ±1.5 centimeters lateral to that of the tibia. The mechanism of pronation requires that the top of the axis of the calcaneus move medially toward the axis of the tibia.

Under those influences which maintain a parallel alignment between the axis of the calcaneus and that of the tibia, the full range of pronation of the fore part of the foot does not take place (Figs. 2-A and 2-B).

A patient (Figs. 3-A and 3-B) had suffered a compound, comminuted fracture of the right femur, in the distal third, complicated by complete severance of the sciatic nerve, four and one-half years before these illustrations were made. For nearly four years after healing of the fracture, he walked unaided by apparatus, without the development of any pronation of the right foot. The gait record (Fig. 4-A) shows that he expressed essentially normal characteristics in respective feet, as compared with the gait record of a normal individual (Fig. 4-B).

The absence of pronation in the right foot prevailed on the basis of osteo-articular relationships which maintained a parallel between the axis of the tibia and that of the calcaneus. In this position, the interlocking mechanism of the calcaneocuboid joint (Figs. 1-B and 1-C) effectively served its function; it stabilized the fore part of the foot on the heel. Also, the left foot of this patient is in good alignment; pronation is not a problem in such a foot. The skeletal characteristics of these feet, thus designed by nature, are functionally efficient; normal alignment is maintained between foot and leg, independent of functions of intrinsic and extrinsic muscles of the foot.

Another point of view is more commonly expressed, but rarely with convincing supportive evidence. It has long been stated that pronation is due to weak muscles. Exercises to increase the strength of muscles are, therefore, prescribed. Such a concept emphasizes only the strength of muscles; it fails to include consideration for the sequence and duration of contraction of muscles which must be reflexly coordinated for normal human locomotion.

There is still another omission. The premise that pronation is due to muscle weakness is not realistic as to the minimum expression of muscle contraction in standing. It is for this reason that in stance the feet have been regarded as "sinking into position".

FIG. 2-A

FIG. 2-B

Fig. 2-A: Structurally normal male feet show pronation under the influence of weight-bearing.
Fig. 2-B: Parallel alignment between tibia and calcaneus is re-established through the use of heel cups with medial elevation.

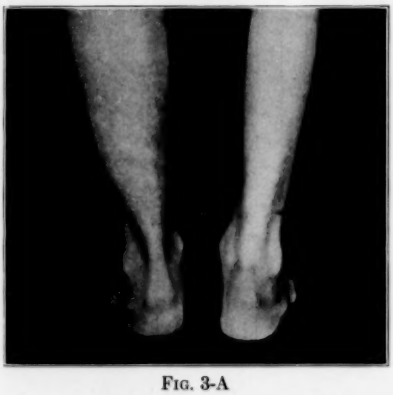

FIG. 3-A

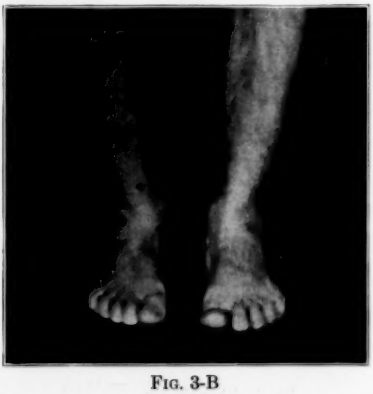

FIG. 3-B

Four and one-half years after compound, comminuted fracture of the right femur and severance of the right sciatic nerve (not repaired), this patient stands and walks with freedom from pronation. The strong calcaneocuboid lock maintains parallel alignment of the right foot and leg in the complete absence of muscle function.

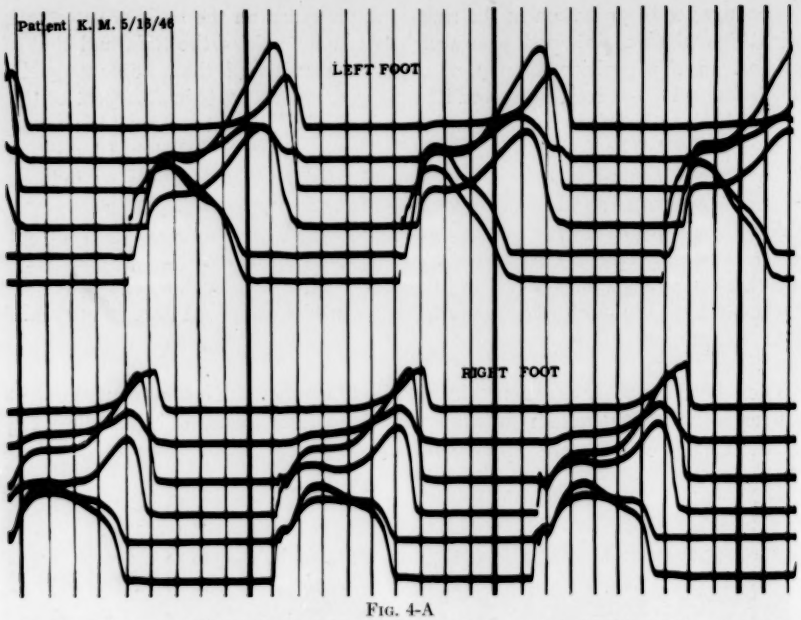

FIG. 4-A

Patient with severed right sciatic nerve shows little evidence of functional limitation, four years after accident. (See Figs. 3-A and 3-B.)

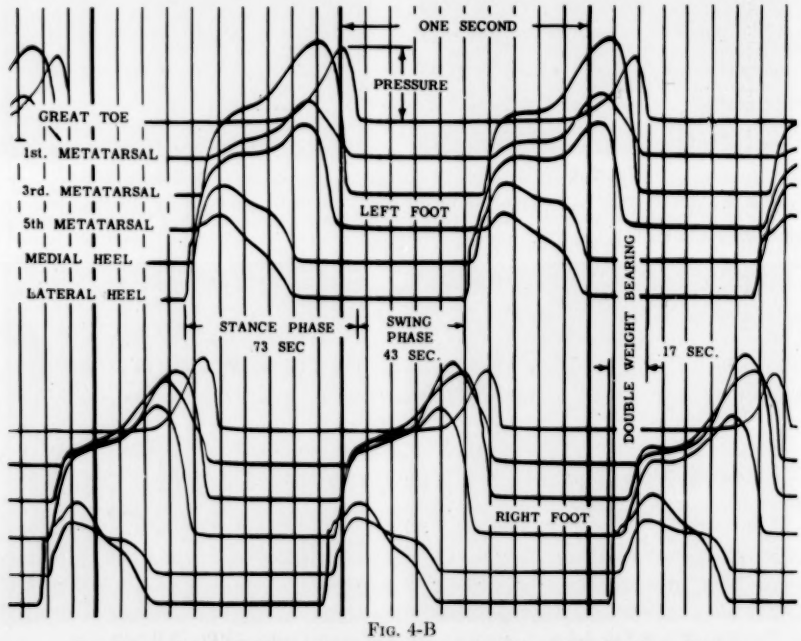

FIG. 4-B

Typical barefoot record reveals normal functional indices of the foot in walking.

A nine-year-old girl illustrates why there is so little evidence in the literature that muscle weakness is the cause of pronation.

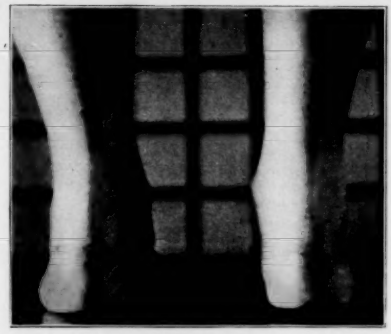

FIG. 5-A

FIG. 5-B

FIG. 5-C

FIG. 5-D

Four years of ballet training resulted in exceptional muscle strength and coordination. Marked pronation in stance (Fig. 5-A) is removed when the child stands on her toes (Fig. 5-B), due to reflex contraction of posterior tibial muscles. Well-developed muscles do not provide protection against pronation in the thoughtless, reflex act of walking (Figs. 5-C and 5-D). During standing and walking, pronation is more marked in left foot than in right.

After the child had had four years of ballet dancing, her mother became concerned about a painless left hallux valgus. Bilateral pronation was noted (Fig. 5-A). It was worse on the left when standing; when walking, there was no less pronation of either foot. When she stood on her toes (Fig. 5-B), the characteristic morphology of pronated feet was erased on each side. In the latter position the posterior tibial muscle was reflexly contracted, in contrast with such functional requirement of the posterior tibial in the act of standing and walking.

This patient is an exception in only one respect. All nine-year-old girls have not practised ballet dancing for four years. Despite the unusual strength and coordination of muscles which she had thus acquired, she did have significant bilateral pronation. Observation of such combined relationships is frequent in daily clinical experience. Therefore, it seems clear that the time has come to discard an assumption which has been regarded as a fact. Prevailing evidence does not support the view that pronation is due to weak muscles.

Pronation will prevail in childhood whenever the functional characteristics of skeletal structures favor its presence, even though the extrinsic muscles of the foot are of normal strength. A degree of pronation requiring treatment in childhood calls for application of Wolff's law, as illustrated by the following case:

Photographs were taken of a boy, aged twelve years, after five years of treatment (Fig. 6-A). Conventional metal plates had been used in an unsuccessful effort to relieve pain in and referred to the feet. During this time, physical activities had been restricted by discomfort to a level far below normal. His pronation was worse on the right and was

FIG. 6-A

FIG. 6-B

Fig. 6-A: Five years of treatment with metal plates had failed to relieve either pronation or associated symptoms in this twelve-year-old boy.

Fig. 6-B: Maintenance of parallel alignment of the axes of the tibia and calcaneus was accomplished through the use of shoes. At sixteen years of age, the patient was able to stand and walk barefooted without significant pronation, and was completely symptom-free.

accompanied by the appearance of abnormal physical and functional characteristics.

Treatment over a period of four years was limited to the use of shoes which maintained a parallel between the axis of the calcaneus and that of the tibia. At sixteen years of age, this patient stood and walked barefooted without pronation of the left foot and with only slight pronation of the right foot (Fig. 6-B). While attaining this end-result, he became symptom-free.

In the first case, the patient was protected from pronation by inherent functional characteristics of the osteo-articular structure, despite the total loss of sensory and motor function below the level of the right knee. In the second case, the patient had severe bilateral pronation, despite unusually well-developed strength and coordination of intrinsic and extrinsic muscles. In the third case, unusually severe pronation and accompanying physical and functional limitations had been unsuccessfully treated by the use of metal plates over a five-year period. Application of the principles described herein resulted in the permanent realignment of the osteo-articular relationships of the foot and leg, with accompanying freedom from symptoms.

The emphasis given to the relationship of the calcaneus to the tibia is not intended to imply that all clinical problems can be effectively alleviated merely by re-establishing parallel alignment between these two related units of the foot. The evidence indicates, however, that re-establishment of such parallel alignment does much to relieve symptoms which may be associated with pronation.

There should be little disagreement with the statement that the metatarsophalangeal area of the foot is the site of most frequent complaints by adults. Volumes have been

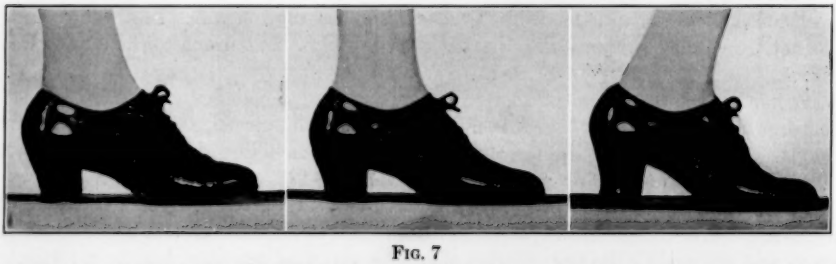

FIG. 7

Three frames from a 16-millimeter film, exposed at 270 frames per second, reveal the effectiveness of the anterior heel as a fulcrum for the fore part of the foot.

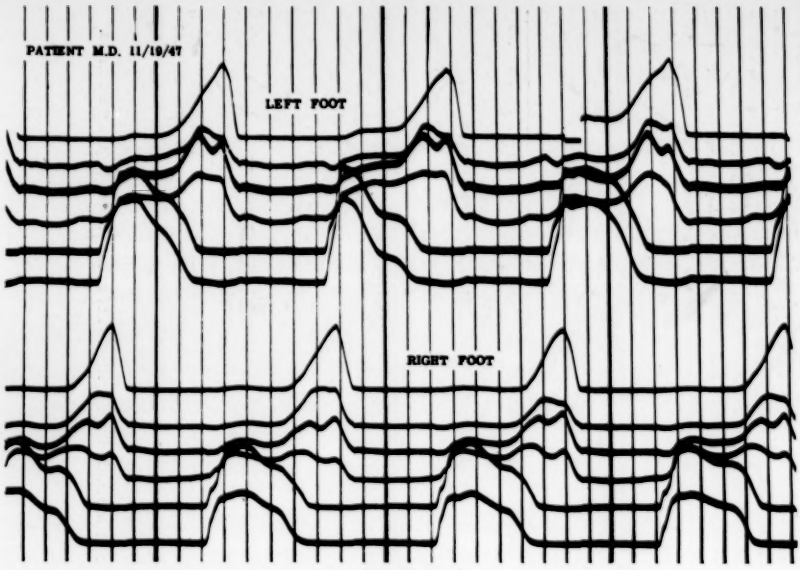

FIG. 8-A

Oscillographic records show limited function of third and first metatarsal heads.

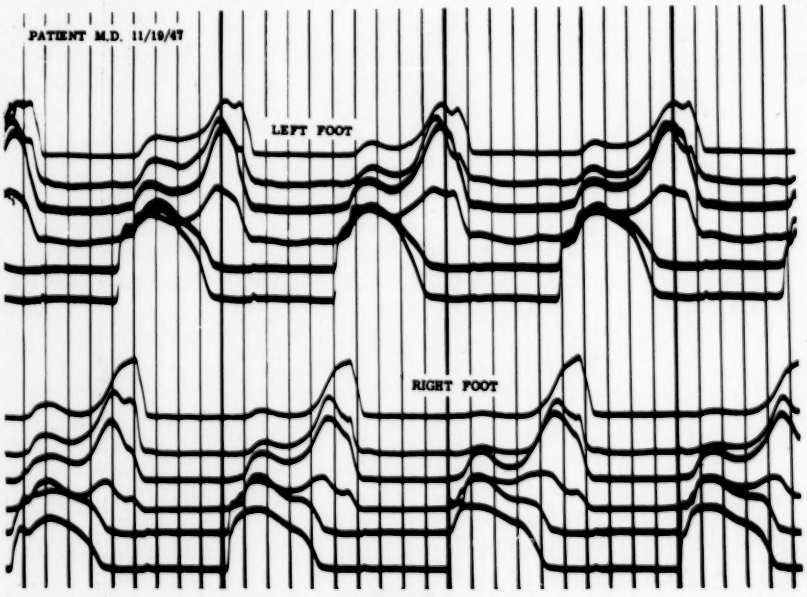

FIG. 8-B

Improvement in function of the fore part of the foot is associated with the bilateral application of the anterior heel. Note smoother flow of pressures throughout step.

written regarding the cause and treatment of "a fallen transverse arch". Less ready agreement is found, however, in the definition of cause, and for this reason there is no readily accepted treatment. Plantar callosities, thinning of the plantar fat pad, limitation in the range of plantar flexion of the lesser toes, particularly the second and third, with or

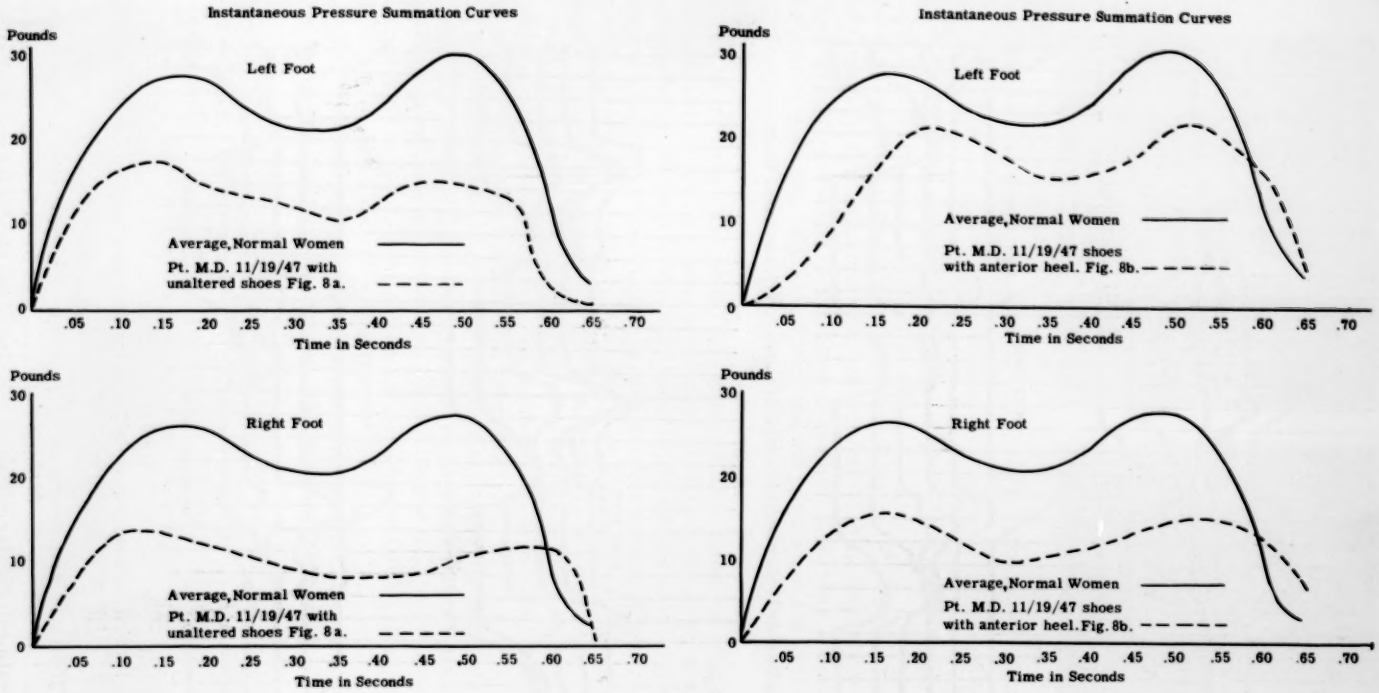

FIG. 9

Summation curves of average normal women's gait, compared with summation curves made before and after application of anterior heel to patient's shoes.

without bunions, hallux valgus, and corns, are commonly associated with complaints of discomfort at this level. These are the expression of structural changes, due to mal-influences which have been long and repeatedly imposed upon the foot.

These mal-influences are due in large measure to a common cause. In certain instances, the beginning of trouble is directly related to a particular pair of shoes. In feet which present a multiplicity of these structural changes and functional limitations, there is evidence of the harm imposed by shoes over a longer period of time.

Early in the nineteenth century, shoes to fit right and left feet were considered an innovation, in marked contrast to the practice prevailing then of using shoes interchangeably. Examination of the literature, however, indicates that this period marks the rediscovery of this practice, which ". . . is a fashion of most remote antiquity"[2]. Whether a shoe was made to fit either foot or an individual foot, however, available literature on the subject emphasizes the prevalence of corns, calluses, and foot deformities attributable to mal-fitting footwear. Today, these common ailments of the feet, due to shoes, are still with us.

At present, there is no generally accepted procedure by which children can assuredly escape the difficulties experienced by their parents. It was more than three-quarters of a century before the making of shoes in pairs became an established practice. Since then, achievements in mass production have been remarkable and the quality of shoes has attained high standards, but the clinical problems associated with feet working in shoes are still present.

Among those concerned with the problems of shoemaking, there is general agreement on one point: Regardless of the quality of material and workmanship, a shoe is no better than the last over which it is made. Such a point of view is of long standing. In 1889, T. S. Ellis stated that the clothing of the foot ought to conform to its functions. To attain this objective, his considerations of the shoe began with the recommendation that "the form of boot-lasts correspond in shape to that of feet in action"[1]. However, there has been essentially no change in the art of last-making; the shape is determined by many factors other than the preservation of foot function.

It is for these reasons that we can account for the heterogeneous variety of devices used in an effort to solve the problems of plantar callosities, corns, et cetera. They are essentially the same as those which have been applied, with varying degrees of effectiveness, for decades. Among these, personal experience has demonstrated the effectiveness of the anterior heel, as used by Hugh Owen Thomas. When properly applied, it is frequently effective in relieving pain from plantar callosities at the metatarsophalangeal level, and assists passive and active exercises to re-establish plantar flexion at the metatarsophalangeal joints, which is so essential to the functional well-being of the fore part of the foot.

The anterior heel (Fig. 7) provides a fulcrum over which the metatarsal phalanges are plantar-flexed. Two clinical advantages result: First is the rapid relief of symptoms, which is more consistent than from any other single mechanism used for relief of discomfort originating in the metatarsal area. Second is the prolonged effect which frequently results from its temporary use. Patients often find that the use of such altered shoes for a varying period, accompanied by passive and active exercises, results in sufficient restoration of comfort, so that they can occasionally use unaltered shoes without discomfort.

The record of quantitative analysis, showing the gait of a patient prior to the application of the anterior heel, is presented (Fig. 8-A). It is evident that the third and first metatarsal heads are not performing their normal function smoothly and rhythmically. Because of the pain in large callosities centering over the third metatarsal heads, the pressures are low and uneven. Propulsion from the great toe is characterized by a sudden sharp rise and decline. Following application of the anterior heel (Fig. 8-B), both records and summation analysis curve (Fig. 9) show a more nearly normal functional pattern. These

changes in function were accompanied by complete freedom from symptoms, and eight months later the callosities were absent.

The inherent weaknesses of the human foot have long been recognized. Its potential strength and methods for best utilizing prevailing structural advantages have not received equal consideration. As long as information is drawn only from visual observation of the living foot and from anatomical studies of the static structure, we shall fail to reach a maximum understanding of the requirements of the human foot for its most efficient functioning. Until recorded evidence capable of quantitative measurement and interpretation is more widely applied, therapy, both conservative and operative, must continue to be instituted and evaluated empirically. This is particularly true in the structurally normal foot, which is dependent upon conservative treatment for the alleviation of pain and fatigue and for the restoration of functional efficiency.

Traditional methods of treatment lean heavily upon "corrective" shoes and the addition of pads, insoles, lifts, et cetera to conventionally designed footwear. The characteristics of conventional footwear and the corrective devices employed in treatment are based upon a study of the foot at rest. Within the scope of these resources, the foot is subjected to an infinite variety of influences, which are the result of opposing theories of shoe design and of therapeutic measures.

Until the function of the foot and the requirements best suited to preserving its function have been thoroughly evaluated on a quantitative basis, such controversial methods must prevail, with the recurrence in successive generations of the same complaints related to the feet. We have presented here some results of the clinical application of instrumentation designed specifically to provide a quantitative definition of the functional requirements of the human foot in action. It is our hope that the application of quantitative measurement to the study of these problems may ultimately lead to the more certain prevention and the effective treatment of common complaints of the human foot at work.

SUMMARY

Pronation in childhood is an expression of deficiency in the function of the intrinsic osteo-articular structures of the foot. By application of the principles of Wolff's law, pronation may be greatly improved or entirely eliminated by the time the child is sixteen. In both children and adults, the preservation of function of the intrinsic and extrinsic structures essential to normal stance and locomotion is required for maximum efficiency and greatest freedom from discomfort. The shoes in which feet must work constitute the major cause of these problems common to successive generations. Excellence in quality of footwear cannot assure that the feet will be free from functional impairment. The structural and functional relationship between foot and shoe is determined by the last over which the shoe is made. The design of lasts has been determined by a combination of empirical influences, without benefit of measurements necessary for the preservation of function of the intrinsic and extrinsic structures essential to efficiency and comfort in stance and locomotion.

Full understanding of the needs of the human foot in action awaits the further application of measurement to the study of foot dynamics. Proved principles can then replace opinion in the design of shoe lasts and in the application of therapeutic measures.

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TIBIAL TORSION *

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The phrase "tibial torsion" has become the commonly accepted term to describe any twist or rotation of the tibia on its longitudinal axis. The term has been used in connection with the rotation which frequently accompanies club-foot, and to explain the crippling results of reductions which fail to secure proper torsional alignment in fractures of both bones of the leg. No emphasis has been placed upon the developmental changes which produce an external rotation of 20 degrees in the normal tibia, or upon the functional and cosmetic handicaps which result when this rotation fails to take place. In adult life, the pigeon-toed gait often produces a psychological disability. There are no reports available to show either the percentage of variations in torsional alignment in the population, or the torsional changes which may be expected during the growth period. Without an understanding of these factors, the problem of correction is difficult to approach satisfactorily.

METHODS OF MEASUREMENT

Tibial torsion may be defined as any twisting of the tibia on its longitudinal axis which produces a change in alignment of the planes of motion of the proximal and distal articulations. The knee and ankle function essentially as hinge joints. The authors have elected, as the base position for measuring torsional variations, that position in which the planes of motion are parallel. Two types of rotational aberration are then possible,—internal and external. Internal torsion is present when the rotation is in the direction of the medial malleolus; and external torsion, when it is in the direction of the lateral malleolus. For recording purposes, the authors have designated the base measurement as zero (0) degrees, internal torsion as minus (−) the number of degrees, and external rotation as plus (+) the number of degrees.

The accurate measurement of torsion presents certain difficulties in the living subject, but may be readily ascertained on the skeletal specimen by means of the tropometer. The longitudinal axis of the tibia is located halfway between the centers of the condylar articulating surfaces proximally, and the malleoli distally. If a steel pin is passed through the proximal articulation parallel to a line drawn through the centers of the articulating surfaces, and another pin is passed through the distal articulating area parallel to a line between the centers of the malleoli, one may visualize the axis of motion of the joints. When the specimen is held so that the proximal articulation faces the observer, the torsion present may be observed by looking along the longitudinal axis of the bone (Fig. 1). The tropometer is used to measure this rotation in degrees. The bone is held in the tropometer by a pin, inserted into the distal end of the bone. The pin through the proximal articulation is fixed to the vertical standard. A protractor, placed directly beneath the distal pin, permits one to ascertain the number of degrees of rotation (Fig. 2). Our most accurate measurements were obtained in this manner.

Approximate measurements can be obtained in the adult patient by the use of a roentgenogram. The film holder is placed beneath the plantar surfaces of the feet, while the patient sits with his knees flexed to 90 degrees and with the medial borders of his feet parallel to the medial borders of his thighs. When the exposure is made with the tube above the knees, the roentgen rays are nearly parallel to the longitudinal axis of the tibia and cast an image of the malleoli and feet upon the film. A line drawn along the medial border of the roentgenographic shadows of the bony structures of the foot will be approxi-

* This study was made possible by the M. J. Connell Research Fund.

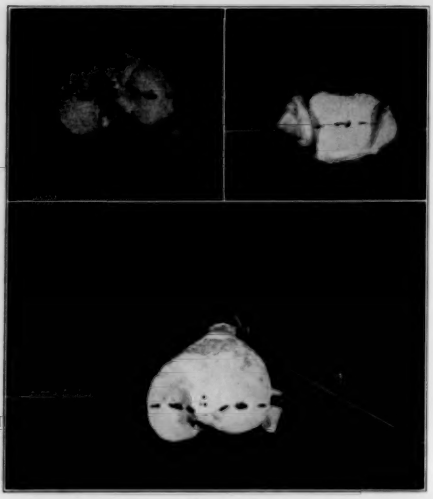

FIG. 1

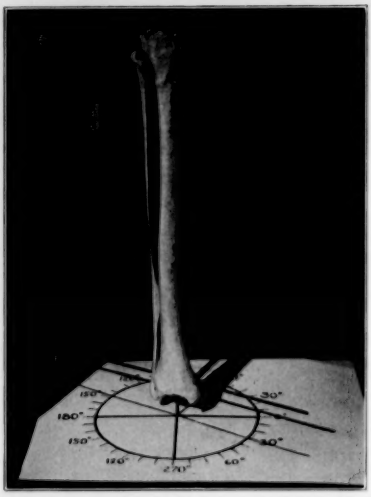

FIG. 2

Fig. 1: Pins inserted through the articular axes of a normal tibia to show external torsion.
Fig. 2: Model demonstrates the method of obtaining tropometric measurements.

FIG. 3

Method employed to evaluate torsion clinically.

mately at a right angle to the articular axis of the knee. The angle formed by the intersection of this line with another line drawn between the malleolar shadows, when subtracted from 90 degrees, will give the measurement of tibial torsion in degrees (Figs. 4-C and 4-D).

This method could not be applied to young children, for their cartilaginous epiphyses cast no satisfactory roentgenographic image. Therefore, a paste, composed of bismuth subcarbonate and collodion, was applied to the skin over the point of maximum palpable projection of the malleoli, in order to demonstrate their location. This technique, while not entirely satisfactory, clearly demonstrated the extremes of rotation in some of the children examined.

In the majority of instances, torsion was estimated on the basis of physical examination alone. The child sat in front of the examiner, with the knees flexed to a right angle. The examiner placed his left hand beneath the popliteal area, supporting the patient's foot from pressure against the floor, while he placed the thumb of his right hand on one malleolus and the index finger on the other. Then, by looking down the longitudinal axis of the tibia, he could estimate the number of degrees of tibial torsion (Fig. 3). This was found to be the most practical method of measurement.

The Adult Tibia

Before any consideration could be given to torsional alterations during the growth period, it was necessary to establish the normal or average structural picture of the adult tibia. Since the knee and ankle act as hinge joints, one would expect them to function most efficiently when their planes of motion were parallel. The authors' measurements do not show this to be the case.

Data were obtained from tropometric measurements of tibiae from forty adult skeletons *. Twenty right tibiae were measured, and the results were as follows: +32, +24, +16, +40, +11, +28, +36, +14, +34, +30, −4, +21, +14, +28, +18, +22, +34, +18, +14, and +12 degrees. The average was +22.1 degrees.

Twenty left tibiae were measured, with the following results: +29, +13, +27, +18, +35, +22, +8, +15, +17, +14, −9, +26, +16, +12, +31, +23, +31, +17, +25, and +27 degrees. The average was +19.8 degrees.

The average of the right and left tibiae combined was +20.9 degrees.

These measurements corroborate the findings of Le Damany, who measured 100 tibiae and found that fifty right tibiae averaged +25 degrees of torsion, while the fifty left averaged +22 degrees, with a combined average of +23 degrees. He also measured five right and eight left tibiae of specimens from a prehistoric age when shoes were unknown, and found that the average torsion was +25 degrees. The five right tibiae measured +30 degrees, while the eight left measured +22 degrees. Shoes have apparently played no part in the development of external tibial torsion. From these data it may be concluded that the normal tibia will exhibit about 20 degrees of external torsion.

Two hundred adults were examined in order to determine the incidence of internal torsion in the adult population. Of 100 women examined, 5 per cent. showed internal torsion; 2 per cent. showed it to a degree severe enough to cause difficulties in walking. Of 100 males examined, 3 per cent. exhibited internal torsion, while 1 per cent. had a pigeon-toed gait sufficient to cause psychological sensitivity.

Because internal torsion is common among the Japanese, the authors examined fifty adults of Japanese extraction, who had been in the United States. Three of these, or 6 per cent., had internal torsion. This percentage was not greatly different from that obtained in the 100 adult Americans examined; however, of eight Japanese who had spent their childhood in Japan, all showed internal tibial torsion. Such a deformity could be expected in Japan, if rotational stresses play any part in abnormal tibial development, for the Japanese have few chairs and sit upon the floor, with their legs folded under them and their feet turned inward, directly beneath the buttocks. Such a posture for several hours a day, with the superincumbent weight of the body producing an internal torsion on the tibia, can scarcely be ignored as a factor in producing a torsional deformity.

TORSIONAL CHANGES DURING THE GROWTH PERIOD

The mean or average tibial torsion is 20 degrees. The authors believe that a variation of 20 degrees—that is, any measurement from 0 to +40 degrees—is consistent with normal appearance and function. Therefore, only those cases with internal torsion (torsion measuring a minus number of degrees by this method) were considered to be abnormal. Likewise, only subjects with severe external torsion (torsion of more than 40 degrees) were considered to be abnormal.

Intra-Uterine Period

During the intra-uterine period of growth, there is an inward rotation of the legs of 90 degrees, as they approach their final position. The limb buds develop at right angles to the trunk and then extend in a lateral direction. The knee joints are developed while in a flexed position, and the plantar surfaces of the feet face the trunk. As they descend on the trunk, the legs rotate 90 degrees internally, so that the knees face anteriorly and the plantar surfaces of the feet point in a posterior direction. The legs usually remain in a flexed position until after birth. Tropometric measurement of these cartilaginous bones is difficult. One nine-month stillborn child was measured, and was found to have 0 and −5 degrees of rotation of the right and left tibiae, respectively. Le Damany measured

* No attempt was made to determine the sex of the individual skeletons.

five infants at birth and found the average to be +4 degrees for the group. These figures indicate that the infant has very little tibial torsion at birth.

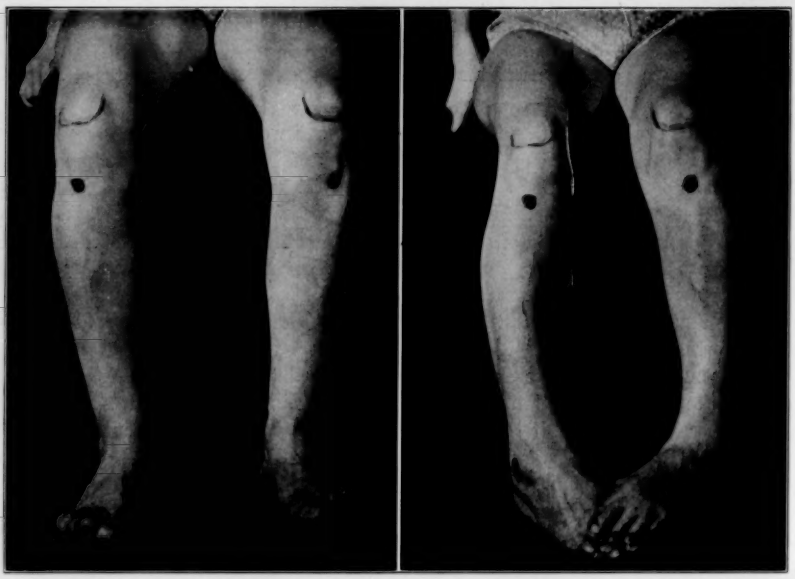

FIG. 4-A

Internal torsion in an adult. When the feet are in a normal position, the patellae and tibial tubercles point outward; when the patellae and tibial tubercles are in a normal position, the lateral malleolus becomes prominent.

FIG. 4-B

Compensation for internal-torsion deformity by external rotation of the knees (left). Non-compensated position which children usually assume (right).

FIG. 4-C

FIG. 4-D

Fig. 4-C: Roentgenograms show internal torsion of −10 degrees on the right and −18 degrees on the left.

Fig. 4-D: Roentgenograms demonstrate external rotation of +13 degrees on the right and +12 degrees on the left.

The First Year

Tropometric examination of infants was almost impossible. One deceased infant, aged twelve months, showed +18 degrees on the right tibia and +12 degrees on the left. Estimation of the torsion by other methods was found to be too inaccurate for the purposes of this study.

The Second Year

Fifty normal infants, all in their second year, were examined clinically. Thirty per cent. walked with the toes turned inward, and on clinical examination showed no evidence of external torsion. One child displayed 15 degrees of internal torsion, bilaterally. Thirty-four children walked with their feet pointed straight ahead or turned slightly outward. One child showed considerable relaxation of the ligamentous structures of the feet, and about 35 degrees of external rotation. None of the fifty children showed any evidence of metatarsus varus or other abnormalities of the feet or legs.

The Period from Five to Seven and One-Half Years

In order to corroborate or refute the widespread opinion that all torsional deformities are corrected spontaneously, approximately 1,500 school children in Los Angeles were examined. The schools in which this survey was carried out were in areas representing an economic cross section of the city, and did not include any children who for some structural deformity had been referred to special corrective classes. Ten per cent. of the 192 boys, who were from five to seven and one-half years of age, showed internal tibial torsion. One half of these, or 5 per cent., had severe deformities. Of 186 girls in the same age group, 8.5 per cent. showed internal tibial torsion.

The Period from the Twelfth to the Fourteenth Year

Four hundred boys were examined, 8 per cent. of whom showed internal tibial torsion; of the 400 girls examined, 9 per cent. had internal torsion.

It is recalled that about 4 per cent. of the adults examined showed some internal torsion, and that in the group aged five to seven and one-half years, a 9 per cent. incidence was found. If we assume that the greatest error in measurement is made in young children, and that adaptive changes have made the condition less striking in the adult, it would appear that relatively little correction of the internally rotated tibia takes place after the

age of seven. In other words, whatever torsion is present in a seven-year-old child will probably still be present when he becomes an adult.

CLINICAL APPLICATION

In this survey, approximately 1 per cent. of the adult population demonstrated a serious degree of internal torsion, indicating that about one million people in the United

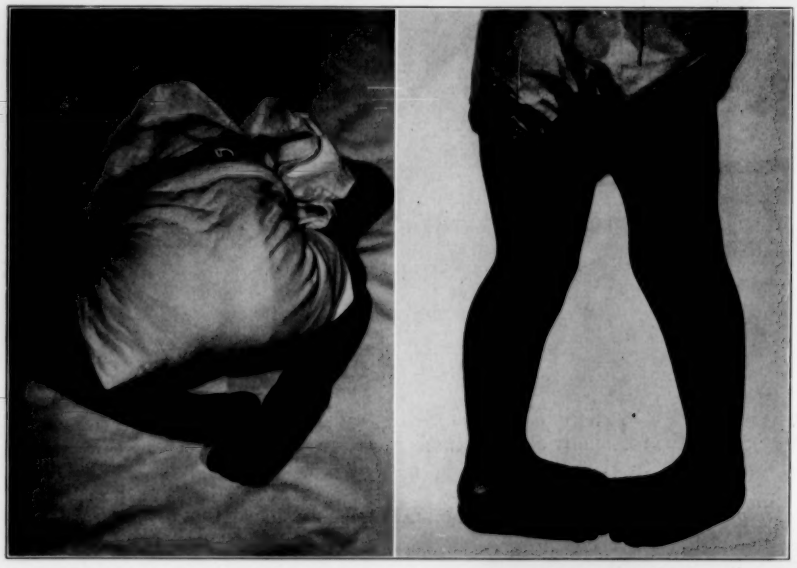

FIG. 5-A FIG. 5-B

Sleeping positions which may play a part in the development of internal torsion in children.

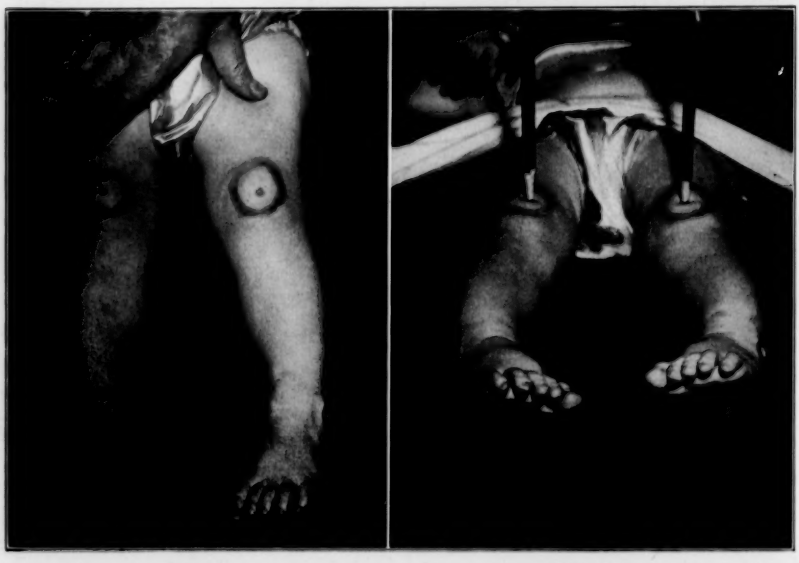

FIG. 6-A FIG. 6-B

Tibial torsion in a child, two and one-half years old.

States may be affected. Because of both the psychological and the functional handicaps which this condition has produced in some of the adults examined, it is apparent that orthopaedic surgeons should be more concerned with these deformities and should institute corrective measures early in the formative years. These deformities are more striking among women, for they are accentuated by high heels and exposed legs. The case history of one such woman is reported:

A white woman, twenty-seven years old, had been aware of deformity of her legs since adolescence; she considered her pigeon-toed gait to be the result of bowed legs. The deformity was a handicap both psychologically and physically. She had suffered no serious childhood diseases or deficiencies, and her family had been assured by their physician that she would outgrow her toed-in gait. Examination of the lower extremities revealed no bowing, but severe internal torsion. She could stand with her feet parallel only by turning her knees outward (Figs. 4-A and 4-B). Roentgenograms of the legs revealed normal bone structure. The internal torsion, measured on the roentgenogram, was −18 degrees on the left tibia and −10 degrees on the right (Figs. 4-C and 4-D).

Approximately eighty children were treated by the authors for internal torsion. In each case the parents were concerned with the toed-in position of the feet while the child was walking. In many cases, the mother volunteered the information that the child was in the habit of sleeping upon the abdomen with the feet turned inward, and with the lower extremities flexed at the hip and knee. Some thought that this might have contributed to the deformity (Figs. 5-A and 5-B). Occasionally, the torsion was accompanied by metatarsus varus or bowing of the lower third of the tibia, but in most cases it was the only deformity present (Figs. 6-A and 6-B).

Two children had external torsion. One, seven years of age, had severe knock-knee and external torsion. He was in the habit of sitting on his legs, with the knees flexed and with the feet externally rotated, so that the medial border of the foot rested upon the floor. Standing, with the feet turned outward to 90 degrees, he was able to flex the knees straight forward. The other patient was a boy of sixteen who, at thirteen years of age, had suffered a fractured spine and paraplegia. Prior to the injury, he had had no deformity

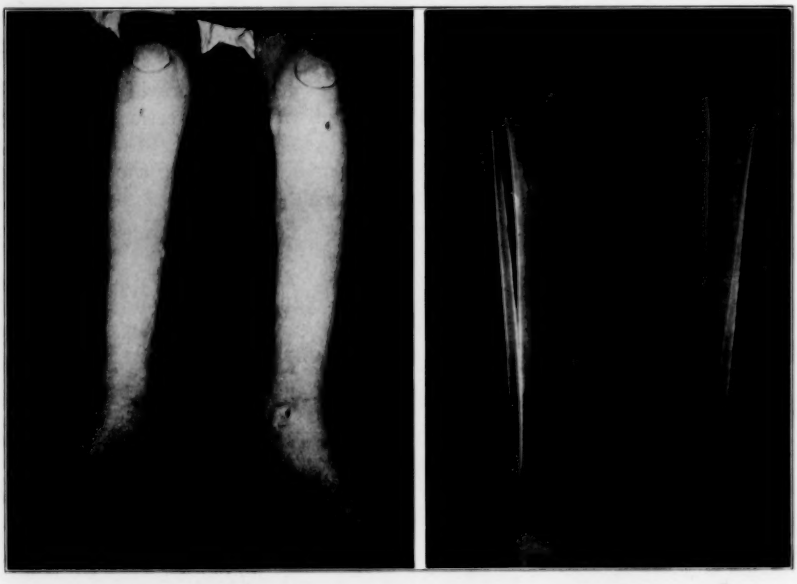

FIG. 7-A FIG. 7-B

Severe external torsion produced by gravity and pressure of bedclothes on legs of a growing paraplegic child.

of the legs, but after three years of recumbency, with gravity and bedclothes forcing his legs into external rotation, a severe deformity had developed (Figs. 7-A and 7-B). Perhaps the same deforming forces which produced such extreme external torsion in this paraplegic play a part in the production of external torsion in the normal individual.

TREATMENT

In the past, some surgeons have treated tibial torsion by osteotomies [1, 2, 3, 5, 7, 8]. Others have employed derotation exercises which the parents perform at home, or have applied a wedge on the outer borders of the soles of the shoes; but for the most part, treatment of this rather common entity has been ignored. Six years ago, one of us (W. S.) instituted a simple and effective treatment which consists of having a child wear a modified Denis Browne splint during the sleeping hours. Shoes are attached to the foot plates, and the plates are fastened in a toed-out direction of 20 degrees at first, and are slowly adjusted until they point outward as much as 45 degrees in severe cases. The length of the bar used to separate the feet has been reduced to six inches to prevent the possibility of the development of knock-knee.

The most frequent comment by the parent at the end of four to six weeks is that the child appears to walk much more normally. This noticeable improvement, however, antecedes actual anatomical correction by four to six months. The authors discontinue use of the splint before all of the correction has occurred, allowing for final compensatory changes in the subsequent growth period.

CONCLUSIONS

1. The normal adult tibia exhibits about 20 degrees of external torsion.
2. Extremes of tibial torsion, internal or external, if permitted to persist, produce handicapped members of our adult society.
3. Infants and pre-school-age children have less external rotation than adults.
4. Normal developmental changes do not correct extremes of torsion to any great extent, especially in school-age children.
5. Positions and other attitudes of posture will produce rotational changes in the tibiae, depending upon the direction of the rotary stress applied.
6. Correction of these deformities is possible in the growth period by the application of a simple night splint, which produces a rotational stress in a direction opposite to that of the deformity.
7. Deformities which are present at three years of age or older should be corrected at that age; younger children with torsional deformity should be observed in order to determine what compensatory changes may occur.

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THE MECHANISM OF THE STRUCTURAL CHANGES IN SCOLIOSIS *

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Structural scoliosis may be defined as that form of lateral curvature of the spine which is accompanied by the development of wedging and deformation of the vertebrae. It should be differentiated from functional scoliosis, which is not accompanied by vertebral wedging or deformation. This paper will attempt to describe the mechanism of development of the *structural* changes in scoliosis.

Certain facts in the clinical behavior of scoliosis are noteworthy. Wedging and deformation of the vertebrae are noted only in curvatures which begin before growth is complete. These changes do not develop in an adult; they stop progressing when growth stops. These facts suggest that a deformity which can occur and progress only during the period of growth must be related to *epiphyseal growth*. This was also suggested by Volkmann and by Bisgard and Musselman, who believed that wedging is due only to asymmetrical vertebral growth. In the report of the Research Committee of The American Orthopaedic Association, a number of clinicians supported the view that "curvature is the result of a growth disturbance at the epiphyseal plate of the vertebrae, possibly related to an osteochondritic process or to epiphyseal trauma with an associated deficiency, either metabolic or dietary".

FIG. 1-A — No growth.

FIG. 1-B — Growth.

Haas's experiment.

Moreover, typical "idiopathic" structural scoliosis does not occur in quadrupeds, and it has been noted that bed rest may halt the progress of such scoliosis in children. In over thirty cases in which the condition was advancing, Cobb kept the children in bed for twenty-two hours per day. Except in one case, no progress was noted after three months. This suggests the familiar concept that the pressure of weight-bearing in the upright position may be important.

The relationship between pressure and epiphyseal growth has been mentioned by various authors, including Appleton, Hueter, and Volkmann. Haas showed that compression of an epiphyseal plate by a wire will arrest growth (Fig. 1-A); the wire itself without compression has no effect (Fig. 1-B). Growth is resumed after the pressure has been removed.

With these factors in mind, the mechanics of a scoliotic curve can be considered. Figure 2 reveals that, in curvatures of the spine, there must be compression of the vertebral bodies on the concave side of the curve and distraction on the convex side, caused by the action of gravitational forces in the erect position. This is also indicated by the narrowing of the intervertebral disc on the concave side and its expansion on the convex side in the roentgenogram of a scoliotic spine (Fig. 3).

The tremendous magnitude which this pressure may assume can be realized from a diagram of the forces acting upon the vertebral body (Fig. 5). Let x represent the distance perpendicularly from the line of center of gravity to the nearest edge of the disc. Let y represent the distance from the pivot point or fulcrum (corner of the body) to the ligament

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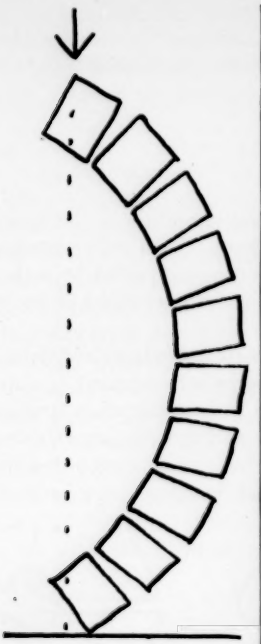

FIG. 2

Fig. 2: Action of superincumbent weight on a curved column of blocks.

Fig. 3: Typical "idiopathic" structural scoliosis.

Fig. 4: Post-thoracoplasty scoliosis.

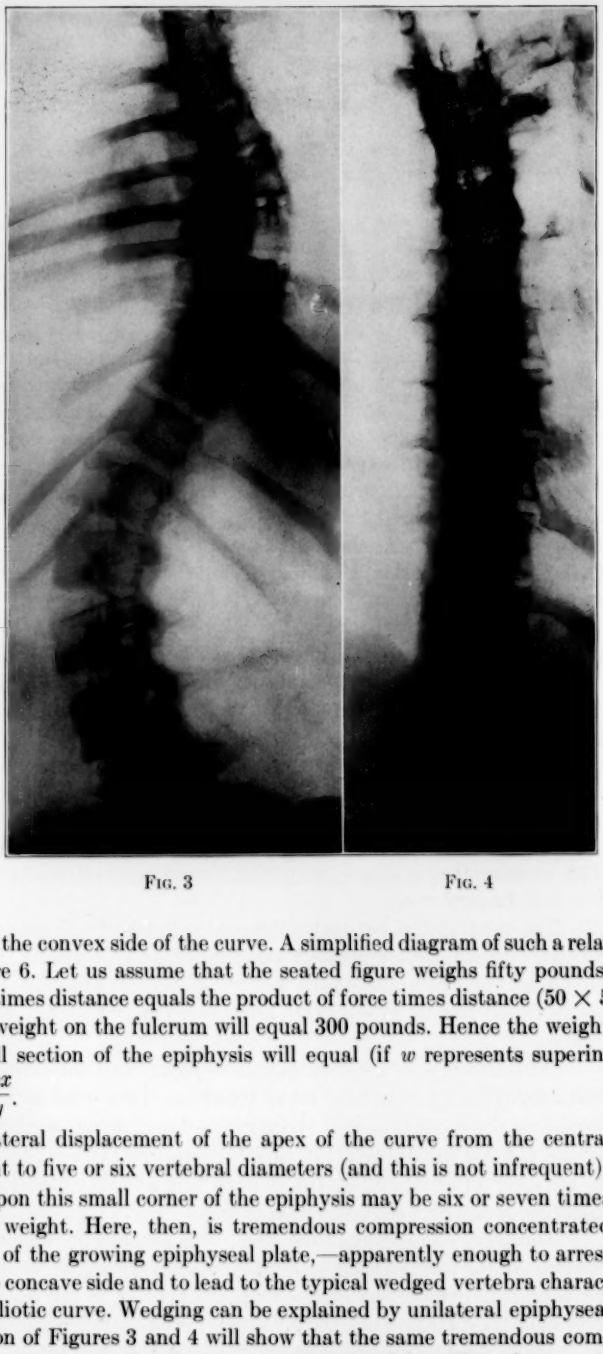

FIG. 3 FIG. 4

or supporting structure on the convex side of the curve. A simplified diagram of such a relationship is shown in Figure 6. Let us assume that the seated figure weighs fifty pounds. Then the product of force times distance equals the product of force times distance (50×5 equals 250×1), and the weight on the fulcrum will equal 300 pounds. Hence the weight concentrated on this small section of the epiphysis will equal (if w represents superincumbent weight) w plus $\frac{wx}{y}$.

In cases where the lateral displacement of the apex of the curve from the central line of gravity is equivalent to five or six vertebral diameters (and this is not infrequent), the weight concentrated upon this small corner of the epiphysis may be six or seven times the total superincumbent weight. Here, then, is tremendous compression concentrated upon a very small section of the growing epiphyseal plate,—apparently enough to arrest the growth in height on the concave side and to lead to the typical wedged vertebra characteristic of the apex of a scoliotic curve. Wedging can be explained by unilateral epiphyseal growth arrest; a comparison of Figures 3 and 4 will show that the same tremendous compression, applied after growth is completed, does not cause wedging. The absence of epiphyseal rings on the concave side (Fig. 18) indicates a similar effect, since the rings are subject to the same pressure as are the epiphyseal plates.

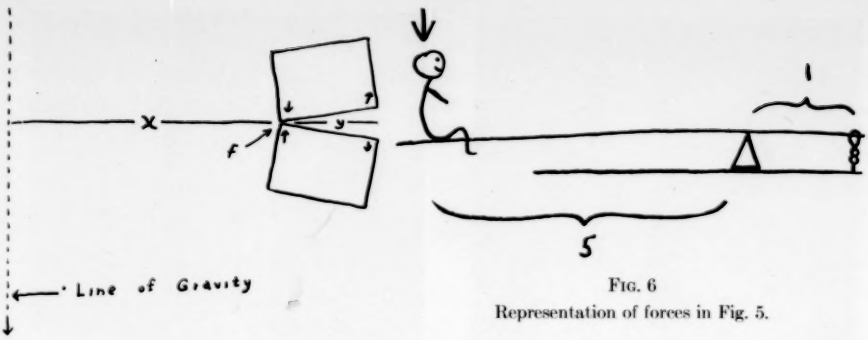

FIG. 5

Forces acting on an apical vertebra in scoliosis.

FIG. 6

Representation of forces in Fig. 5.

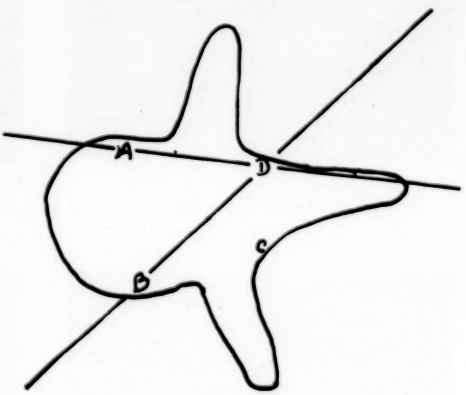

FIG. 7

Diagrammatic representation of vertebrae, as seen from above.

(This is an approximation, and not a quantitative expression of the forces acting upon the epiphysis. It does not take into account the soft-tissue tension or the resistance to stretching on the convex side of the curve, which has the effect of increasing the distance *y* and diminishing the weight on the fulcrum. For example, examination of a specimen of a scoliotic spine at the New York University College of Medicine revealed marked hypertrophy of the *intertransverse* ligament on the convex side. Certainly *y* is equal to more than one vertebral diameter in this case. Neither does it take into account the supportive effect of impingement of ribs and pelvis on the concave side, and the resistance of the rib cage to deformation. Moreover, the sharp corner of the vertebral body is soon flattened off by the inhibition of growth, and a progressively larger area of the body acts as a fulcrum and supports the superincumbent weight, thus diminishing the load per unit of area.)

Examination of a typical vertebra as seen from above (Fig. 7) shows that the normal spine may be considered to be supported at four points, denoted by *A*, *B*, *C*, and *D*. Lateral bending in the normal spine may be considered to take place through the axis *A–D*. If support *A* is depressed by the mechanism described, then lateral bending will take place through the axis *B–D*. Hence the concavity of the curve is directed anteriorly as well as laterally, producing the *kypho*scoliosis seen clinically.

A simple model may be constructed to reproduce these conditions. A set of ordinary wooden blocks (in this case, a child's building blocks) are taken to represent a series of vertebrae. An upper and a lower corner of each is shaved down to represent vertebral wedging (Fig. 8). Two vertical holes are drilled in each, as shown, to receive the cord which binds them together. The cord should have slack enough to allow a little play between the blocks. If the column of blocks is bent laterally toward the intact side, as shown in Figure 9, pure lateral deviation will occur. If the column is bent toward the wedged side, anterolateral deviation occurs, the equivalent of a kyphoscoliosis (Fig. 10).

ROTATION

If the wedged apposing surfaces are lubricated with soap to represent the slippery inter-

FIG. 8
Construction of model.

FIG. 9
Lateral deviation to the intact side.

FIG. 10
Anterolateral deviation to the wedged side.

FIG. 11
Convex-side rotation with vertical compression.

vertebral disc, and the column is compressed vertically (Fig. 11), convex-side rotation appears, exactly as it is seen clinically. The reason for this is immediately apparent. A wedged vertebral body under compression acts exactly like a wedge and is squeezed out laterally when pressure is applied (Fig. 12). This can be seen roentgenographically, especially in children, although in adult specimens the overlapped vertebrae may build up a bony buttress to meet the adjacent overhang. That this is a passive process is in accord with Steindler's observation that "no muscle can shift a vertebral body in horizontal direction".

Some of the rotation occurs by the actual rotation of a vertebral body across the one adjacent (between the individual bodies), although this is limited by the surrounding

ligaments and especially by the limited excursion of the posterior joints. Much of the rotation occurs by plastic torsional deformation of growth *within* the individual vertebrae, against the resistance of the posterior articulations. The internal structure of the body follows accurately the lines of force occurring in a structure such as that shown in Figure 2. (The torsional deformation of the middle of the curve against the ends should also be taken into consideration.) The bodies at the apex of the curve are subjected to internal plastic deformation, analogous to that seen when a grape is expelled from its skin. The bodies at the upper and lower ends of the curve show deformation in response to the lines of force which are oblique to their vertical axes, leading to the formation of the "oblique" or "quadrilateral" vertebrae found in this location.

This plastic deformation ceases when epiphyseal growth ceases. Hence one may postulate that it is produced by an oblique or sideways deflection of growth by the pressure forces at the epiphyseal region. It is suggested that the slow deformation in slipping of the capital femoral epiphysis is produced similarly. The deflection of the newly formed juxta-epiphyseal bone may be considered as analogous to the deflection of streams of water, issuing from pipes at right angles to a moving stream. In both cases, the deflection is in the direction of the sideways force. Appleton has reported similar pressure-induced deformations of growing bone in the experimental animal. Further observations on this mechanism will be reported by the author in a subsequent article.

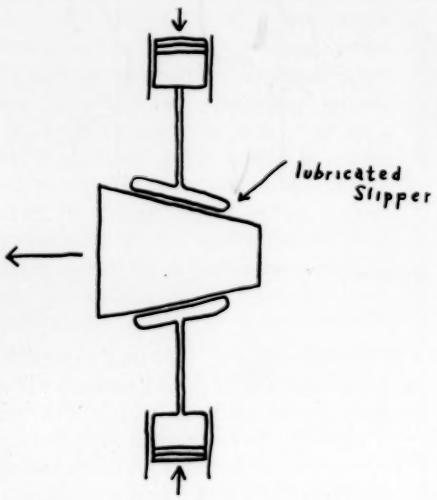

FIG. 12
Action of a wedge under compression.

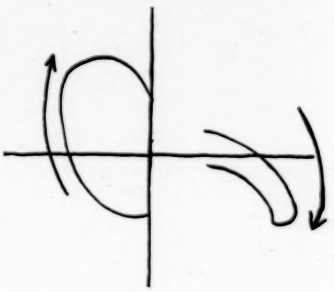

FIG. 13
Rotation in an apical vertebra, as seen from above.

In a diagrammatic representation of a wedged apical vertebra as seen from above * (Fig. 13), the body is squeezed over or deflected to the convex side of the spinal curvature. It is known that no muscles act upon the body to distort it in this fashion, and that this passive plastic deformation in the direction of increasing rotation about the facets is the result of the wedge action described here. However, the spinous process is also deviated,—toward the *concave* side of the curvature. This cannot be the result of wedging, since it is not wedged and is not in contact with any other spinous process. The deformation must be the result of forces in soft tissue, since only soft tissues are in contact with the spinous process. Moreover, this deformation is in the direction of increasing rotation; hence there must be some muscular or ligamentous component of rotation.

In Figure 14, the dots represent the tips of the spinous processes in a scoliotic spine. The line connecting these dots represents the interspinous and supraspinous ligaments.

* The transverse processes are not shown, as their deformation has been described previously by Steindler.

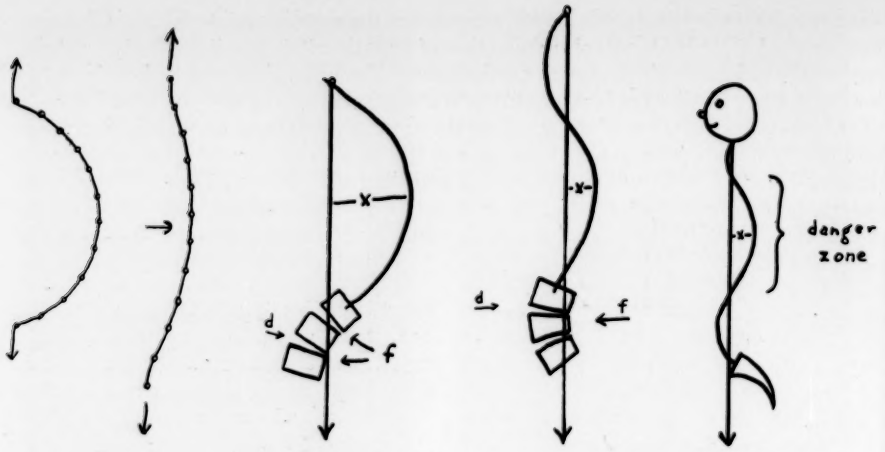

FIG. 14 FIG. 15 FIG. 16 FIG. 17

Fig. 14: Extension of a curved line.
Fig. 15: Recurvature of the ends of a curve.
Fig. 16: Fig. 15 after development of compensatory curves.
Fig. 17: Anteroposterior curves of a normal spine.

When these ligaments are put under tension (in a kyphoscoliosis), they tend to straighten out the curve, as shown. The long spinal muscles on each side of these ligaments will also tend to straighten out under tension. Thus the spinous processes in the middle of the curve will be deviated to the concavity of the curve, while the bodies remain in their former position, resulting in convex-side rotation. The muscle contribution to rotation is similar to the action of the rubber bands in the model described by Rogers. These were tense (and hence yielded convex-side rotation) in both flexion and extension of the model. Lovett[7], in 1905, found that side bending in excised spines was associated with convex-side rotation (same direction as in Figure 13) only in flexion, when the interspinous ligaments are tense.

It is this mechanism which accounts for the small amount of rotation seen in unwedged post-thoracoplasty scoliosis, but the importance of this mechanism in the production of rotation is relatively small, compared to the importance of wedging (Figs. 3 and 4).

The Development of Compensatory Curves

In scoliosis with a single major curve (Fig. 15), the ends of the curvature are bent back or recurved, due to the attempt of the patient to level off his pelvis and head. The vertebral bodies in this region are unwedged at first; hence these compensatory curves are functional, not structural.

It will be noted in a roentgenogram of a scoliotic spine that, as the spine begins to recurve, the discs begin to be compressed on the *opposite* side of the bodies and on the concave side of the new curve (Fig. 15, *d* and *f*). Pressure is thus falling on the corners of the bodies at *f;* distraction is present at *d*. This may lead to inhibition of growth at *f* with wedging of the vertebra and conversion of the "functional" compensatory curve into a "structural" curve.

The first or main curve need not be structural (wedged) in order to initiate the development of a functional counter curve. Many purely functional curves have functional counter curves which have developed concurrently. They have never deviated sufficiently from the weight-bearing line to cause wedging, and these well-compensated curves are usually static and do not progress to a structural scoliosis.

Steindler noted that, when structural scoliosis is arrested spontaneously, it is by the

natural development of compensatory curves. His compensation treatment is designed to aid the development of this process, which, of course, is the principal means of correction in all methods of treatment, since, as far as is known, the wedged apical vertebrae cannot be corrected. He stated: "That a spine well compensated by the development of a triple scoliosis, well aligned, will maintain its balance under favorable conditions is a matter of almost daily experience".

Figure 16 demonstrates why this is successful. A factor determining the amount of weight acting upon the corner of the vertebral body, as shown earlier, is the *x* distance. Compensation diminishes this distance and thus diminishes the compression of the epiphysis. Haas showed that growth was resumed when compression had been removed; hence with both sides of the epiphysis growing, the deformity does not progress.

Risser mentioned the relationship between pressure and epiphyseal growth ("Hueter-Volkmann's epiphyseal pressure rule"), and used this principle to induce the formation of structural compensatory curves. He noted that, by forcibly recurving the ends of the scoliotic curve in a plaster jacket for a prolonged period of time, he could produce wedging of the vertebrae (at point *f* in Figure 16). He suggested that this was due to inhibition of growth by the pressure produced by the plaster jacket. The rationale for the value of the flexion position recommended by Risser will shortly become obvious.

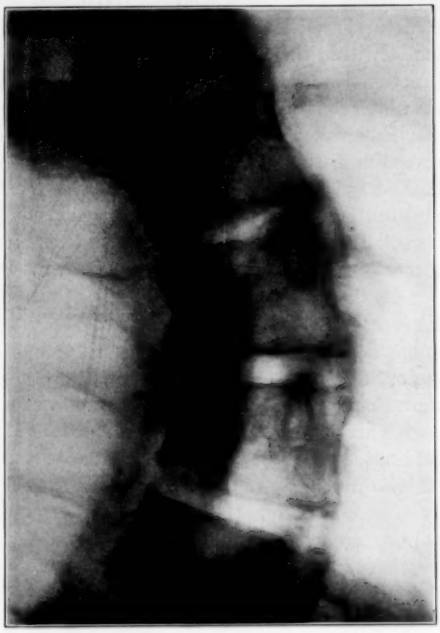

FIG. 18
Enlarged view of apex of curve in Fig. 3.

One more point remains to be made. Figure 17 shows the anteroposterior curves of the normal spine. In the cervical and lumbar regions, the normal lordosis relieves the anterior portions of these regions (the bodies) from part of the superincumbent weight, throwing it more upon the posterior articular facets. This explains why the region from approximately the second thoracic to the second lumbar vertebra is the danger zone for the development of wedging. The cervical vertebrae are practically never wedged. The lumbar vertebrae are only partially protected, due to the greater superincumbent weight they carry (and due also to the forward displacement of the line of gravity in low thoracic kyphoscoliosis). They are sufficiently protected, however, so that they rarely become wedged, despite the frequency of functional curves due to inequality of limb length. Steindler quotes Schulthess's statistics, which show that the vast majority of curves have their apices between the third thoracic and the second lumbar vertebrae. Of this number, 11.7 per cent. occur at the first and second lumbar, the predisposing condition being the habitual attitude of flat back. "If, on the other hand, he succeeds in compensating his anteroposterior curve by developing a round hollow back, then his spine is comparatively safe against lateral deviation."

Hence, when the *x* distance (Fig. 17) is increased by habitual postural kyphosis, excessive weight is thrown upon the thoracic vertebral bodies. This is more evenly distributed, and never of the order of magnitude of the excessive compression in scoliosis. It is suggested that the epiphyseal rings, which appear at about the fourteenth year of

life, are compressed by this mechanism (see the effect of pressure in Figure 18), leading to "vertebral epiphysitis" or adolescent kyphosis, which the author considers to be a pressure-induced growth disturbance. Steindler stated that Mau, describing the microscopic findings in vertebral epiphysitis, found no real ossification process.

Another possible factor, that of increased superincumbent weight, was probably operating in the cases described by Virchow, who, according to Steindler, "found this condition in the Australian negroes, who from their early adolescence are in the habit of carrying weights upon their shoulders, or of pulling carts with forward flexed trunk".

DISCUSSION

It has been shown how a functional, non-wedged curve can progress into a fixed structural scoliosis. Although a discussion of the etiology of the preceding functional curve is not within the scope of this paper, it may be assumed that the initiating cause of the functional curve, in some cases at least, may continue to contribute to the structural scoliosis which follows.

Functional curves may be divided into two groups. In one group there is a known causative factor; in the other, the cause is considered obscure. These latter are usually labeled as idiopathic or habitual; they are extremely frequent, almost universal, and the multitudinous discussions of the etiological significance in their causation of sitting and standing posture, right-handedness, attachment of the diaphragm, preponderance of right thoracic curves, et cetera, are well known.

In the first group, the initiating cause of the displacement is clear. In this group fall the congenital anomalies, and those following poliomyelitis and empyema. Congenital anomalies, such as hemivertebrae or oblique fifth lumbar vertebra in the lower lumbar region, do not usually lead to structural scoliosis, for the reasons outlined earlier. In the thoracic region they may or may not progress, depending upon whether the compensating curves are acute enough to keep the distance from the weight-bearing line within the critical limit. Poliomyelitis with its attendant muscle changes can produce a functional curve. This is quite likely to progress, because the natural process of compensation is handicapped by muscle abnormalities, and so structural scoliosis is relatively frequent. It is also apt to be severe when it becomes structural, because of the difficulty of establishing compensatory curves and because of the lack of muscle support on the convex side, which decreases the effective y distance. There is probably no direct effect on the epiphysis from the poliomyelitic infection. Were this so, a bilateral complete trunk paralysis would have a bilateral epiphyseal arrest with resultant severe kyphosis. This does not occur.

Empyema and thoracoplasty furnish an obvious mechanism for curvatures. The differences in types of scoliosis developing after onset in childhood and adult life have been pointed out. It is not strictly true that there is *no* wedging in curves beginning after the age of sixteen. Some slight wedging may occur, due to arrest of growth of the rings, up to the age of twenty-five, when they unite with the rest of the vertebral body (Fig. 18).

Whatever the cause of the functional curve, as soon as it has produced a deviation exceeding a certain critical value, the factors described in this paper come into play and the spine has embarked on the course of epiphyseal compression and structural scoliosis. It is possible that such factors as rapidity of growth, heredity, and sex, and pathological processes, such as rickets, may modify the quantitative relationship between pressure and growth arrest.

Obviously the best treatment is prevention, by correcting postural deviations, whether in the anteroposterior or the lateral plane, or both, before they progress to structural changes. In a severe curve, plaster jackets and braces cannot completely relieve the epiphysis of the pressure induced by the superincumbent weight, tremendously multiplied as it is by the mechanical arrangement which obtains. Recumbency, of course, removes the superincumbent weight completely. A combination of these two methods (jackets plus

recumbency) would seem to offer the better prospect of successful conservative treatment.

SUMMARY

1. The vertebral deformation of structural scoliosis can be explained by an asymmetrical disturbance of epiphyseal growth by pressure.

2. "Vertebral epiphysitis" is a related lesion.

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DISCUSSION

Dr. Henry F. Ullrich, Baltimore, Maryland: Aside from agreeing on the spelling of the word "scoliosis", I believe that those of us who treat curvatures agree on but one other point,—that is, that scoliosis is a deformity of the growth period and, therefore, is intimately related to epiphyseal growth and activity. Beyond that point, especially in the field of mechanics of the deformity, one is apt to wander into theoretical considerations, draw conclusions from them, and apply those conclusions to the living, growing spine, where they are not strictly applicable because other factors are present. In dealing with this complex deformity, let us always keep in mind the fundamental differences between facts and opinions, and let us remember that opinions may become facts if substantiated by correct, accurate, and controlled observation.

That there is tremendous asymmetrical pressure on epiphyseal plates cannot be denied, but there must be other factors to provoke this asymmetrical pull and to initiate this unilateral increase in compression force. We do not know how much pressure is required to produce the effects that Dr. Arkin has described. Concerning rotation, I believe the spine does not behave as a square cross section, or even as a cylindrical cross section, but that the neutral axis of each vertebral body is different at each level; and, because of this, different mechanical forces act on different vertebrae. For example, the forces acting on the first thoracic vertebra are entirely different from the forces acting on the third, fourth, fifth, or sixth thoracic vertebra.

The spine, I believe, rotates in order to accommodate itself in the easiest manner to its acquired position. Hence, rotation is a function of curvature and varies directly with it.

Most of us now have abandoned the concept that a compensatory curve, no matter how severe, will straighten, once the deforming tilt has been removed by jacket correction or other means. Especially in a growing individual, this occurs up to the ability of the spine to straighten within the limits of the structural changes present, and little, if any, beyond that. After the growth period has passed, balance and correction—but not beyond the point of the spine included in a fusion area—are factors to keep in mind, in order that a reverse deformity may not be produced.

I sincerely hope that Dr. Arkin's essay will provoke more sound thinking regarding scoliosis, especially with respect to the primary factors involved in producing curves of unknown etiology.

Dr. Joseph C. Risser, Pasadena, California: Dr. Arkin's paper is very timely. He refers to a law of bone growth that is recognized infrequently. In 1862, after work and dissection on the foot, Hueter concluded that wherever there was not direct apposition of joint cartilaginous surfaces in the growing individual, there was an increase in the growth of epiphyseal bone. Volkmann, in 1882, clarified that law and applied it

to scoliosis. The importance of Hueter-Volkmann's epiphyseal pressure rule in growing bone is illustrated by slides.

The first slide shows a tuberculous spine in a nine-year-old boy, with destruction in the inferior portion of the first lumbar vertebra. The typical tuberculous destruction, with hazy translucence over the entire area and narrowing of the intervertebral space, may be seen. Fusion was accomplished over the diseased area and included one joint above. Two years later, the disease was arrested by virtue of immobilization, leaving a residual bone defect in the inferior portion of the first lumbar vertebra. Three years later, after continued vertebral growth, roentgenograms showed that the vertebral body just below the area of destruction had grown upward into the defect, illustrating the contention made by Hueter.

The same principle is illustrated in another nine-year-old boy, who had a thoracic curvature of the spine. The thoracic area had been fused previously, leaving a residual thoracic curve without compensation in the lumbar area, and causing a list in the direction of the thoracic curve. In order to overcome this deformity, the spine was bent markedly against the thoracic curve, creating a sharp compensatory curve in the thoracolumbar area, just below the thoracic fusion. This permitted a marked separation of the vertebral bodies at the thoracolumbar area, creating a compensatory convexity on this side. Fusion was then carried down to include two vertebrae in this compensatory curve. Four years later, with rapid vertebral growth, the vertebral bodies had built up into the space created by the bending of the thoracolumbar curve, again illustrating Hueter-Volkmann's epiphyseal pressure rule.

In another nine-year-old boy, who had not only a lateral curve but also some wedging of the thoracic vertebrae, fusion was carried throughout the thoracic area following correction of his lateral curvature. Four years later, there was a very solid fusion and the wedged vertebrae had actually built up, so that, instead of being wedged anteriorly, the vertebrae were relatively normal in shape. The slides and illustrations show the effect of pressure and release of pressure upon joint cartilaginous surfaces or upon rapidly growing epiphyseal areas. Such epiphyseal areas are not only vulnerable to pressure, but become more vulnerable when there is any lack of integrity of the growing bone, as illustrated by epiphyseal fragmentation.

A girl of thirteen years had a lateral curvature with the apex at the first lumbar vertebra. In the lateral view, marked epiphyseal fragmentation and wedging were noted at the first lumbar and the adjacent vertebrae. This young lady had a low basal-metabolic rate, which suggests a lack of essential bone-building materials. Therefore, we see that not only are mechanical factors involved in the control of growth of bone, but also factors influencing bone physiology.

Apical vertebral rotation is a concomitant part of lateral deviation. Rotation is dependent upon the relation of the segments or vertebral bodies in the spinal column. In the lumbar region, contact between vertebral bodies at the posterior articulations is more eccentrically located than in the upper portions of the spine. Because of this eccentric relationship, the lumbar vertebral bodies will rotate earlier. In the thoracic spine, the contacts are less eccentrically placed and rotation, therefore, is a later development in lateral curvature. The initial change in the upper thoracic area is manifested earlier in wedging than in rotation. This was specifically mentioned by Dr. Ullrich.

It is important to determine the completion of vertebral growth; this cannot be ascertained by laws of averages, but must be determined physiologically for each individual. The best physiological sign we have found is the development of the iliac apophysis. This development apparently takes place about the time of completion of growth of the epiphyseal plate of the vertebral body. It is difficult to determine the completion of growth of these vertebral plates, or epiphyseal plates of the vertebral bodies, but very easy to determine the development of the iliac apophysis. Therefore, as a physiological sign, the development of the iliac apophysis is a reliable method of determining cessation of vertebral growth.

This is shown clearly in a girl of fourteen (Slide). Ten years later, we notice the same amount of deformity (Slide). The growth of the iliac apophysis had been completed at the age of fourteen, indicating cessation of vertebral growth and a static condition of the lateral curvature.

DR. ALVIN M. ARKIN (closing): I think Dr. Risser, Dr. Ullrich, and I all agree that the structural changes were due to growth arrest resulting from pressure.

Dr. Risser's apt illustration of the lumbar vertebrae, in which he produced wedging by a plaster cast, is very appropriate. You will remember that the line of gravity usually protects these lumbar vertebrae if there is a lumbar lordosis, and I suggest this is the reason Dr. Risser likes to use a flexion jacket, so that he can get the weight on these bodies, stop growth on one side and allow it on the other, and thereby produce the wedging.

The rotation in the lumbar spine, free of wedge deformity, is slight compared to that found when wedging is present. This is due to the action of the tight ligaments and muscles (not pathologically tight). Tension is normally present in the ligaments and muscles in the posterior regions of the spine. These structures, under tension, cause rotation of the middle of the curve against its ends.

THE PATHOLOGY OF NEURAL-ARCH DEFECTS

A Dissection Study

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In the literature, the etiology of spondyloschisis has been ascribed to divergent causes, but in particular to trauma. If the latter theory is held to be acceptable, then there are certain facts which must be reconciled with it,—such as the existence of multiple anomalies which involve not only the pars interarticularis, but also the lamina and the ligamentum flavum. In order to clarify this matter and to establish these facts, the following dissection study is presented.

Acute traumatic spondyloschisis (fractures through the partes interarticulares on both sides) do occur, and may occur in a normal spine free from anomalies. If diagnosis is made in such cases at the time of injury, and if suitable protection is provided, bony union results.

The specimen for this dissection study was obtained from the cadaver (No. C17) of a white male, forty-four years old. Roentgenographic studies had previously revealed bilateral defects in the neural arch of the fifth lumbar vertebra and a spondylolisthesis. That portion of the lower back where these lesions were located, and the associated structures—the last four presacral segments and the sacrum—were removed from the cadaver.

Following the removal of the overlying musculature, the elements of the posterior segments of each lumbar vertebra were exposed. These included the spinous processes, the laminae, the partes interarticulares, and the articulations between the articular processes (the intervertebral joints), together with their associated ligaments. All the laminae were then viewed as during a laminectomy or a spine fusion, and they appeared superficially to be of equal size and inclination. The isthmi or partes interarticulares (terms to be used interchangeably) of all the vertebrae except those of the fifth lumbar were at a somewhat deeper (or more anterior) level than were the laminae, and their inclinations were almost directly caudad-cephalad. The isthmi of the fifth lumbar were more prominent in comparison, being on a level with their respective laminae; and toward the cephalad direction they deviated laterally in a more oblique fashion. These isthmi appeared to be deformed, were more rounded, and were narrower in thickness than those of the vertebrae above. They were well encapsulated in a fibrous sheath which seemed to be a part of the ligamentum flavum, as well as continuous with the capsules of the intervertebral joints above and below.

Neural-Arch Defect on the Right Side

The outstanding finding was that accessory ligaments, not hypertrophy, were demonstrated in the ligamentum flavum.

The ligamentum flavum between the laminae of the fourth and fifth lumbar vertebrae on the right appeared to form a square (Fig. 1). In the medial upper quadrant, a modified round ligament arose separately from the surface. From thence it inclined obliquely and caudad, terminating in the medial aspect of the fibrous encapsulation of the defective isthmus. In the lateral upper quadrant, a separate fan-shaped ligament was seen, arising from its relatively wide base along the caudad margin of the lamina of the fourth vertebra; from there it converged to a thickened termination in the fibrous encapsulation of the isthmus, cephalad to the attachment of the other ligament (Fig. 2). The pattern of varia-

FIG. 1

FIG. 2

Fig. 1: Sketch of the posterior oblique photograph shows the defective right pars interarticularis of the fifth lumbar vertebra. Compare with right posterior oblique roentgenogram of same area (Fig. 10).

1: Intervertebral joint cephalad to defect in pars interarticularis, formed by the inferior articulating facet of the fourth lumbar and the superior articulating facet of the fifth lumbar vertebra.

2: Intervertebral joint caudad to the defect in the pars interarticularis, formed by the inferior articulating process of the fifth lumbar vertebra and the articulating process of the sacrum.

3: The lamina of the fourth lumbar vertebra.

4: The lamina of the fifth lumbar vertebra.

5: The ligamentum flavum between the laminae of the third and fourth lumbar vertebrae.

6: The ligamentum flavum between the laminae of the fourth and fifth lumbar vertebrae. In the lateral upper quadrant, the fan-shaped ligament is evident. Medial to *6*, a small plaque of bone was found in the substance of the ligament. The round ligament, originating above *6*, was detached before the photograph was made.

7: The defective right pars interarticularis of the fifth lumbar vertebra, ensheathed in its fibrous capsule, which is continuous with the joint capsules above and below and with the fan-shaped and round ligaments.

8: The supraspinous ligament.

9: The normal right pars interarticularis of the fourth lumbar vertebra.

Fig. 2: Sketch of the round and fan-shaped ligaments of the ligamentum flavum, adjacent to the right defective pars interarticularis of the fifth lumbar vertebra.

1: The intervertebral joint cephalad to the defective pars interarticularis.

2: The intervertebral joint caudad to the defective pars interarticularis.

3: The lamina of the fourth lumbar vertebra.

4: The lamina of the fifth lumbar vertebra.

5: The ligamentum flavum between the laminae of the third and fourth lumbar vertebrae.

6: The ligamentum flavum between the laminae of the fourth and fifth lumbar vertebrae, showing the round and fan-shaped ligaments converging to the fibrous encapsulation of the defective pars. (The sketch shows these attaching to the distal rather than to the proximal segment of the pars.)

7: The defective pars interarticularis, ensheathed in a fibrous capsule.

8: The supraspinous ligament.

tion of this ligament was, therefore, not that of uniform thickening throughout (hypertrophy), but rather it was characterized by the presence of accessory ligaments arising from it.

The fibrous sheath enclosed a cavity about the defective pars, which was separated from the joint cavity above by a fibrous septum.

An incision fashioned a flap from the encapsulating sheath and its continuity with the joint capsules above and below (dotted line, Fig. 1); this flap was reflected medially in the direction of the spinous processes (Fig. 3). The articulating facets of the intervertebral

FIG. 3

FIG. 4

Fig. 3: Sketch of the right posterior oblique photograph shows the fifth lumbar vertebra. The fibrous sheath has been reflected medially toward the spinous processes, exposing the defective pars.

1: The reflected fibrous sheath is held back with a pin, showing from above downward the interior or synovial lining of the capsule of the intervertebral joint, the orifice in the sheath between *1* and *8* and adjacent to *1*, and, just lateral to it, the fibrous septum which separates the joint space above from the space about the defective pars below. The latter space did not appear to have a synovial lining.

2: The intervertebral joint cephalad to the defective pars interarticularis. The sketch shows, not only a subluxation of the joint (*2*), but also separation, the latter improvised for the sake of clarity of detail.

3: The intervertebral joint caudad to the defective pars.

4: The lamina of the fourth lumbar vertebra.

5: The lamina of the fifth lumbar vertebra.

6: The ligamentum flavum between the laminae of the third and fourth lumbar vertebrae.

7: The ligamentum flavum between the laminae of the fourth and fifth lumbar vertebrae.

8: The defective pars interarticularis. The defect is seen at the cephalad extent of the pars, and the three connecting ligaments are evident,—the cephalad, the middle, and the caudad.

9: The supraspinous ligament.

Fig. 4: Sketch of the right posterior oblique photograph following removal of the fibrous sheath about the defect, including the capsules of the intervertebral joints above and below, as well as the fan-shaped ligament.

1: The intervertebral joint cephalad to the defective pars shows marked amount of subluxation. (Again, the separation of joint surfaces is a convenience, assumed for the clarity of detail in sketching.)

2: The intervertebral joint caudad to the defective pars. There is normal approximation of the opposing facets.

3: The lamina of the fourth lumbar vertebra.

4: The lamina of the fifth lumbar vertebra.

5: The ligamentum flavum between the laminae of the third and fourth lumbar vertebrae.

6: The ligamentum flavum between the laminae of the fourth and fifth lumbar vertebrae, now denuded of fan-shaped and round ligaments.

7: The defective pars interarticularis of the fifth lumbar vertebra, showing the segments joined by the cephalad, middle, and caudad ligaments.

8: The supraspinous ligament.

9: The normal pars interarticularis of the fourth lumbar vertebra.

joint cephalad, and a fibrous septum between the joint cavity and the cavity surrounding the defective isthmus caudad, were thereby exposed. The synovial lining of the joint cavity presented shallow plications adjacent to its attachments, suggesting the possibility of synovitis. The exposed intervertebral joint disclosed a marked subluxation, the superior articulating facet of the fifth vertebra covering only the lower half of the inferior articulating facet of the fourth vertebra. A hypertrophic spur projected from the posterior aspect of the rim of the facet of the inferior articulating process of the fourth vertebra.

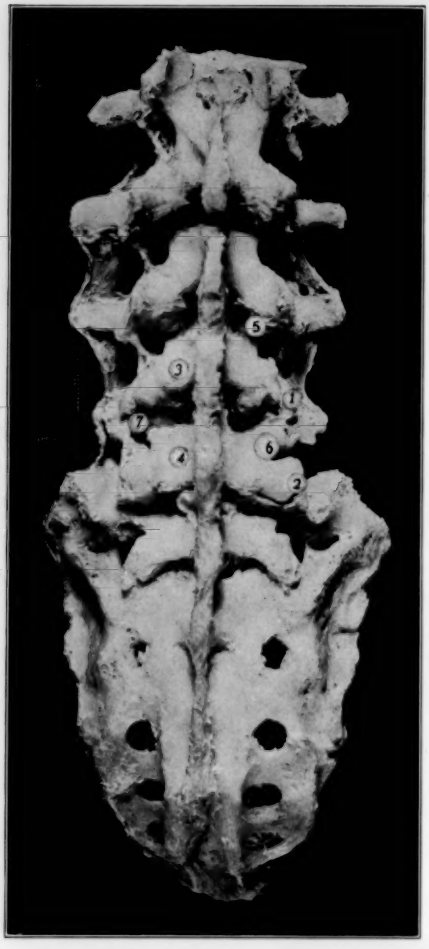

FIG. 5

FIG. 6

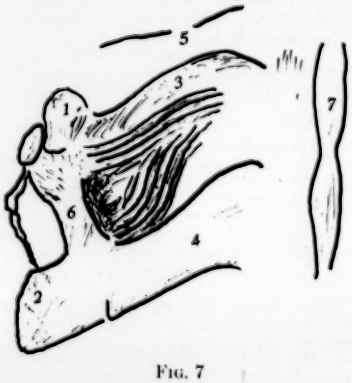

FIG. 7

Fig. 5: Photograph of the posterior aspect of the specimen at the termination of dissection study. Apparently, there has been a partial developmental lumbarization of the first sacral segment and a sacralization of the first coccygeal segment.

1: The intervertebral joint on the right, cephalad to the defective pars.
2: The intervertebral joint on the right, caudad to the defective pars.
3: The lamina of the fourth lumbar vertebra on the left.
4: The lamina of the fifth lumbar on the left. Note the abnormal conformation of the anterior cephalad extent of both laminae and their pseudo-articulations with the pedicles. Between *4* and *7* on the left, the ligamentous attachment is shown, joining the lamina with the posterior aspect of the pedicle. Note also the absence of a pars interarticularis on the left, between *4* and *7*.
5: The normal pars interarticularis of the fourth lumbar vertebra on the right.
6: The defective pars interarticularis of the fifth lumbar on the right.
7: The pedicle of the fifth lumbar vertebra on the left.

Fig. 6: Sketch of the posterior oblique photograph of the laminar defect of the fifth lumbar on the left. Compare with left posterior oblique roentgenogram of same area (Fig. 12).

1: The intervertebral joint cephalad to the defect.
2: The intervertebral joint caudad to the defect.
3: The lamina of the fourth lumbar vertebra.
4: The lamina of the fifth lumbar vertebra.
5: The ligamentum flavum between the laminae of the third and fourth lumbar vertebrae.

6: The ligamentum flavum between the laminae of the fourth and fifth lumbar vertebrae.
7: The fibrous sheath at site of the pars interarticularis of the fifth lumbar vertebra.
8: The supraspinous ligament.
9: The normal pars interarticularis of the fourth lumbar vertebra.

Fig. 7: Sketch of the ligamentum flavum between the fourth and fifth lumbar vertebrae on the left, showing linear patterns.
1: The intervertebral joint cephalad to the defect.
2: The intervertebral joint caudad to the defect.
3: The ligamentum flavum.
4: The lamina of the fifth lumbar vertebra.
5: The lamina of the fourth lumbar vertebra.
6: The fibrous sheath of the defect.
7: The supraspinous ligament.

The fibrous septum separating the two cavities was reinforced along its posterior margin by an extension of the rounded portion of the fan-shaped ligament described previously. The latter traversed the fibrous encapsulation, extended tautly across the cavity as part of the fibrous septum, and was attached to the bone of the cephalad segment of the isthmus. The second round ligament, which was followed to the fibrous encapsulation, traversed this sheath, extended tautly across the cavity parallel to the ligament above, and was attached to bone immediately adjacent to it. Upon removal of the reflected flap *in toto* (Fig. 4), the fan-shaped ligament was found to be a continuous part of the encapsulating sheath. The defective isthmus, the articulating facets, and the ligamentum flavum were now exposed.

The defect in the right pars interarticularis was joined not by fibrocartilage, but by ligaments. Pseudo-articulation was found between the pedicle and the abnormal prolongation of the cephalad portion of the lamina; this was also joined by ligaments.

The defect was found at the upper end of the isthmus. The cephalad segment was 2 millimeters in length. The caudad or lower segment measured 1.2 centimeters. There was a 3-millimeter defect between the two bony segments. The length of both segments including the defect was 1.7 centimeters. By comparison, the length of the intact right isthmus of the fourth lumbar was 5 millimeters. The defect itself was not filled with fibrocartilage, but the junction of the two segments was well stabilized by fibrous ligaments. Three ligaments were present,—a cephalad, a middle, and a caudad. The cephalad and caudad ligaments appeared to be non-elastic, and they extended along the respective sides of the defect. (As noted, the defective isthmus was in an almost horizontal position.) The ligaments were intimately attached to both bone fragments. The cephalad ligament measured 3 millimeters in width, while the caudad one—a well-developed fibrous band—measured 1.8 centimeters in width. The middle ligament interposed between the ends of the fragments was of equal thickness, but was more flexible. It appeared to have been non-functional, as far as stress and strain are concerned. A microscopic section of this ligament revealed adult fibrous tissue without any evidence of cartilaginous or osteoid tissue.

Removal of the ligamentum flavum was undertaken next. Within the section immediately over the dura, the site traversed in seeking a ruptured nucleus pulposus, a small, thin, wafer-like plaque of bone was encountered. When the lateral extent of the ligamentum had been taken away, an abnormal conformation of the lamina appeared (Fig. 5). Its cephalad margin—that portion of the lamina between the base of the spinous process and the superior articulating process—extended horizontally to the pedicle to which its irregular edge (measuring 1.5 centimeters in width) was attached by intervening ligamentous tissue. This junction of the two was fixed beneath and was strongly stabilized by the wide caudad ligament of the adjacent defective isthmus described previously.

Neural-Arch Defect on the Left Side

The ligamentum flavum contained singular line patterns: the lateral half was divided into two leaflets; the superficial or posterior leaflet presented a round fibrous sheath along its lateral margin in place of the normal isthmus.

FIG. 8

FIG. 9

FIG. 10

Fig. 8: Anteroposterior roentgenogram.
1: Spinous process in central alignment.
2: The inferior articulating process of the fourth lumbar vertebra on the right.
3: The superior articulating process of the fifth lumbar vertebra on the right. The anteroposterior view shows to greatest advantage the subluxation of this joint.
4: The shadow of the fifth lumbar partially imposed on the first sacral segment.

Fig. 9: Lateral roentgenogram.
1: The body of the fifth lumbar vertebra, showing its anterior displacement on the sacrum, almost complete disappearance of the intervertebral disc beneath, and hypertrophic spurring of its anterior surface.
2: The first sacral segment, showing reactive sclerosis of its posterior superior surface, and hypertrophic spurring of its anterior marginal aspect.
3: The defect between the lamina and pedicle can be seen immediately above and to the right of *3*. The contiguous spinous process shows slight posterior displacement with reference to that of the one above.

Fig. 10. Right posterior oblique roentgenogram. (Film has been reversed.)
1: The superior articulating process of the fourth lumbar vertebra is shown just to the right of *1*.
2: The pars interarticularis of the fourth lumbar vertebra.
3: The inferior articulating process of the fourth lumbar vertebra.
4: The superior articulating process of the fifth lumbar vertebra.
5: The defect in the pars interarticularis of the fifth is seen between *4* and *5*.
6: The articulation between the inferior process of the fifth lumbar vertebra and sacrum.

Attention was then directed toward the dissection of the defect on the left side. The fibrous sheath over the defective segment of the arch was much thinner than that encountered on the opposite side, and was more regular and direct in alignment (Fig. 6). It formed a thin, tubelike structure, extending from the cephalad and lateral aspects of the lamina of the fourth vertebra, adjacent to the lower intervertebral joint, to that portion of the pedicle immediately posterior and caudad to the intervertebral joint above. Palpation revealed a softness and pliability in its mid-section. On casual examination, the ligamentum flavum of the involved interspace appeared as normal as those in the interspaces above. However, closer examination revealed two line patterns in its fibers, which did not constitute separate ligaments. One linear pattern arose from the medial upper quadrant of the membrane, extended directly laterally, and terminated at the junction of the rounded fibrous sheath with the superior articulating process, in the lateral upper quadrant (Fig. 7). The other linear pattern, originating in the same focal area in the medial upper quadrant of the membrane, swept in an obliquely curved pattern downward and lateral to the outer lower quandrant, affixing itself to the base of the rounded fibrous sheath at its point of attachment to the lamina.

Incisions to outline the flap over the defect were made in the same manner as on the opposite side. In cutting through the fibrous sheath, which was presumed to enclose a defective isthmus, only two longitudinal flaps were produced rather than the opening into an enclosure of bony isthmic defects. The fibrous sheath was not an encapsulating structure at all, but rather a solid, round modification of the more superficial of the two layers constituting the lateral half of the ligamentum flavum. The incision had merely divided the full thickness into two longitudinal flaps. Further dissection to expose the joint above did not show any degree of subluxation. The synovial lining was not remarkable. The facet edges showed minimal hypertrophic irregularities.

Immediately deep to the divided rounded fibrous sheath was a cavity, indicating the absence of the pars interarticularis. The deep layer of the lateral half of the ligamentum flavum covered the floor of the cavity, which also included the posterior aspect of the pedicle and the projecting portion of the lamina. The superficial or posterior layer measured 5 millimeters; and the deep or anterior layer, 3 millimeters. Microscopic section of the posterior layer revealed areas of calcified cartilage. After the ligamentum flavum had been completely removed, the same type of attempted articulation of the abnormal cephalad prolongation of the lamina with the pedicle was seen, similar to that described on the right side, and again free of any fibrocartilage (Fig. 5). The ligament deep or caudad to this junction was more rudimentary and elastic in appearance than was that on the right side, and measured one centimeter in width.

ROENTGENOGRAPHIC FINDINGS

The defect in the neural arch is quite obvious in the lateral view (Fig. 9). The intervertebral disc between the displaced body of the fifth vertebra and the sacrum has almost disappeared. The condensation of bone and spur formation are evident along the opposing

FIG. 11

FIG. 12

Fig. 11: Intervertebral joints and associated processes, outlined on left posterior oblique roentgenogram. (Film has been reversed.)
1: Superior articulating process of the third lumbar vertebra with shadow of transverse process superimposed, resembling eye and bill of a duck.
2: The pars interarticularis (isthmus) of the third lumbar vertebra, resembling neck.
3: The inferior articulating process of the third lumbar vertebra.

Fig. 12: Left posterior oblique roentgenogram. (Film has been reversed.)
1: The superior articulating process of the fourth lumbar vertebra.
2: The pars interarticularis of the fourth lumbar vertebra.
3: The inferior articulating process of the fourth lumbar vertebra.
4: The superior articulating process of the fifth lumbar vertebra.
5: Between *4* and *5* is the defect created by the absence of the pars interarticularis of the fifth vertebra on this side.

surfaces of the sacrum. In the right posterior oblique view (Fig. 10), the line of defect is faintly seen across the involved isthmus. There is no evidence of reactive sclerosis at this site of breach in continuity; no sclerosis is evident in the related intervertebral joints above and below the defect. Galluccio pointed out the "bow-tie" appearance of the pars with its associated articular processes, as a means of orientation in studying oblique views. In the author's experience, orientation is simpler by visualizing the shadow of the superior articulating process with its superimposed transverse process as the bill and eye of a duck, the isthmus being the neck. If the neck is discontinuous or broken, it may be concluded that a defect in the pars is present (Fig. 11). The left posterior oblique view (Fig. 12) is significant in this respect, since no neck is seen on the "duck" of the fifth vertebra, indicating that the isthmus is absent. In the presence of this relatively great defect of bone, the facets of the intervertebral joints above and below are free from subluxation (as shown in the

anteroposterior view, Figure 8, and in the dissection of the specimen). There is evidence of reactive sclerosis and hypertrophic lipping of the inferior articular process of the fifth vertebra on this side, where it hooks over the articulating facet of the sacrum.

CONCLUSIONS

In discussing the relative significance of neural-arch defects and split spinous processes (bifid spines), Willis stated: "When the defect destroys the integrity of that portion of the bony arch between the vertebral body and the inferior articular processes as in the case of a bilaterally separate neural arch the condition is much more serious. Here we have the anchorage of the spine depending merely upon a fibrocartilaginous union with ligamentous and muscular support." Again, "Rupture of the synchondrosis [defect] is more serious than the ligamentous injury which accompanies it. The separated bone ends are covered with cartilaginous material and, therefore, show no tendency to reunite." In this particular specimen, the defect in the isthmus on the right was united not by fibrocartilage, but by unusually strong fibrous ligaments, and was ensheathed in a fibrous capsule. The isthmus on the left was completely absent, and there was no evidence of fibrocartilaginous replacement. The pseudo-articulations between the pedicles, and the abnormal prolongations of the cephalad portions of the laminae, were effected by ligaments and not by cartilage.

Findings in this specimen were: (a) the complete absence of an isthmus on one side, and, on the other side, a defective isthmus strongly fixed by ligaments and three times the length of the normal isthmus above; (b) the abnormal conformations of the laminae and their pseudo-articulations with the pedicles; (c) the structural variations noted in the ligamentum flavum on each side; and (d) the associated presence of a partial developmental lumbarization of the first sacral segment and a sacralization of the first coccygeal segment.

NOTE: The author wishes to acknowledge his gratitude to Dr. Mildred Trotter, Professor of Gross Anatomy, Washington University School of Medicine, for her kindness in making this specimen available.

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NUTRIENT ARTERIES OF THE VERTEBRAL BODIES*

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The venous plexus in and around the vertebrae have been described frequently, but little information is available concerning the course of arterial supply to the vertebral bodies. An effort has, therefore, been made to determine this.

Patten has described the formation of the vascular system by coalescence of blood pools throughout the embryo, and the formation of the aorta by fusion of primitive dorsal aortae which develop from arteries arching from the heart around each side of the pharynx.

FIG. 1-A

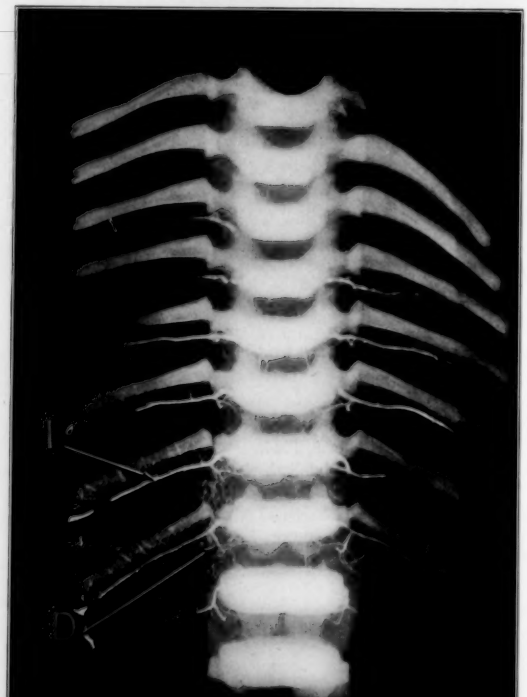

FIG. 1-B

Fig. 1-A: Lateral roentgenogram of a full-term foetal spinal column with opaque vascular injection of the aorta. *A* indicates the aorta; *I*, the intercostal artery. Note notching of anterior surfaces of the vertebral bodies and lesser density of the bodies in their mid-portions. The longitudinal anastomosis of arteries in the neural canal is well shown.

Fig. 1-B: Anteroposterior view of the same column after removal of the aorta. *I* shows the intercostal artery; *D*, the dorsal division of the artery. Note anastomosis of the intercostal arteries and incomplete ossification of the cartilaginous neural ring.

* Part of an address to the Alumni of the Hospital for Ruptured and Crippled and the Hospital for Special Surgery, New York City, October 29, 1948.

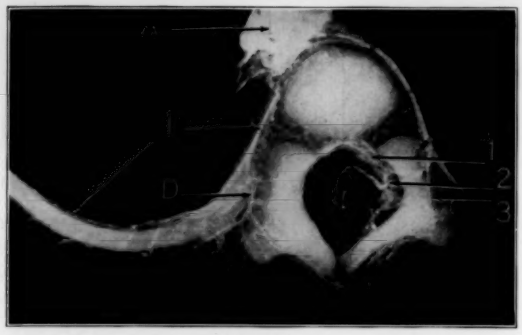

FIG. 2-A

Fig. 2-A: Vertical view of one of the thoracic vertebrae. *A* shows the aorta; *I*, the intercostal artery; *D*, the dorsal division. *1*, *2*, and *3* are the first, second, and third branches of the dorsal division. Note the many fine arteries penetrating the periosteum and the perichondrium.

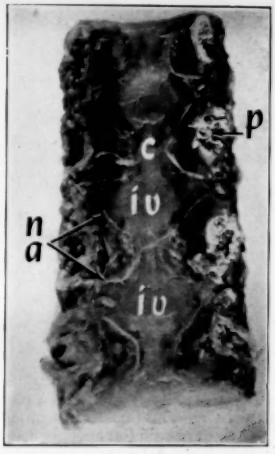

FIG. 2-B

Fig. 2-B: Photograph of the posterior surface of the same vertebrae after removal of the neural arches. *p* is the amputated pedicle stump; *c*, the vertebral centrum; *iv*, the intervertebral-disc area (*c* and *iv* are covered by the posterior spinal ligament); *na*, the nutrient arteries, the first branches of the dorsal division of an intercostal or lumbar artery.

Each of the primitive aortae, before they fuse, gives off branches which mark the spinal column into segments. After fusion, the paired segmental vessels, which become intercostal and lumbar arteries, extend dorsally from the aorta and cross the middle of the lateral surfaces of the vertebral bodies, one on each side. The larger element of each runs laterally, anterior to the lower border of the ribs and the transverse processes, to supply the thoracic and abdominal walls. A large branch is given off in the trough formed by the vertebral bodies and transverse processes. It traverses the intervertebral foramen and divides into three terminal branches, one to the posterior surfaces of the two adjacent vertebral bodies, another to the spinal cord and its membranes, reaching the cord by way of the ligamentum denticulatum, and the third to the posterior vertebral processes and surrounding soft structures (Figs. 1-A, 1-B, and 2-A).

The branches to the cord anastomose freely with the anterior and posterior spinal arteries which lie on the respective surfaces of the cord, extending from within the skull to the end of the cord. Thus far, this vascular supply of the vertebrae is described in most texts of anatomy.

It was formerly taught that the principal blood supply of the vertebral body entered through foramina on its anterior surface, the fovea centralis. More recently, a nutrient artery has been described, entering the posterior surface.

The first branch of the dorsal division of the intercostal or lumbar artery divides within the spinal canal, one terminus running upward and medially across the posterior surface of the vertebral body under the posterior spinal ligament, to enter a foramen at about the center of the body. The other terminus runs downward and medially to a similar entrance in the center of the body of the next distal vertebra. Thus there are four diagonal arteries, two from each side, converging to enter the center of the posterior surface of each vertebra. They may enter through a common foramen or each may have its own individual entrance. At this point the bone structure is cancellous, or even cavernous, and the arteries may coalesce or remain more or less separate. From here, their branches radiate to all parts of the centrum (Fig. 2-B).

During the tenth and eleventh weeks of embryonic life, ossification of the vertebral bodies is under way. This process extends from the center of the body along the radiating arteries; it takes place more rapidly in the upper and lower thirds of the body, the central

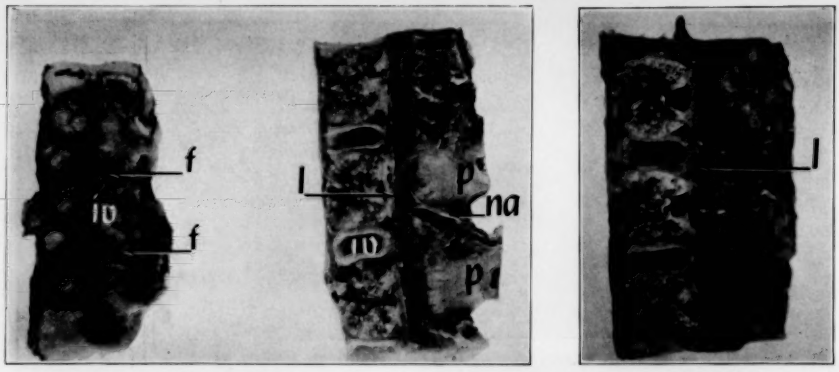

FIG. 3-A FIG. 3-B

Fig. 3-A: Shown at left is a photograph of the posterior surface of three lumbar vertebrae, with the neural arches and posterior spinal ligament removed.

At right is a similar specimen, split sagittally. *f* indicates foramen for entrance of the nutrient arteries; *iv*, intervertebral disc; *c*, centrum; *l*, posterior spinal ligament; *p*, pedicle stump; *na*, nutrient arteries, entering the neural canal between the pedicles and disappearing under the ligament to reappear in the cavernous bone of the centrum.

Fig. 3-B: Similar to Fig. 3-A (right view), enlarged to show the cavernous ossification of the centrum, radiating from the center.

portion lagging behind. It is this layer of delayed ossification that gives the spool-shaped appearance in lateral roentgenograms of embryonic vertebrae. The notch shown by roentgenograms on the anterior surface of the vertebral body (Fig. 1-A), sometimes referred to as the fovea centralis, is due to relative lag in calcification of the cartilaginous centrum, not to the entrance of nutrient arteries. The foramina seen on the anterior surface of the centra are exits for veins, not entrances for arteries.

The nutrient arteries enter the posterior foramina from a layer of loose areolar tissue beneath the posterior spinal ligament, which bridges the concave posterior surfaces of the bones, being attached only at their upper and lower borders. It is thickened in the midline and weak laterally, where the vessels perforate it. It does not fuse with the annulus of the intervertebral discs as completely as does the anterior ligament (Figs. 3-A and 3-B).

Considerable importance has been ascribed by Schmorl, Beadle, and other writers to the radiating corrugations that are found on the surfaces of young vertebral bodies when the epiphyseal plates have been stripped off. These, however, are found on the diaphyseal ends of all growing long bones and represent the usual waves of growth along the vascular tree. A leg of lamb, a femur of a young pig, or a fowl's femur shows a similar concentric-gear appearance when stripped of its epiphyseal plates.

Blood-borne infections of bones are most apt to become localized in the end arteries of newly formed bone, where the vessels are easily thrombosed and the tissue is less resistant. They occur, therefore, in the subepiphyseal ends of the vertebral bodies, as they do in other bones that grow from their ends.

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CHANGES IN ELASTIC ADIPOSE TISSUE *

BY JOHN G. KUHNS, M.D., BOSTON, MASSACHUSETTS

The fatty tissues of the body vary in firmness according to their supportive function. Soft adipose tissue forms an almost continuous layer beneath the skin, surrounds viscera, and fills cavities throughout the body [10]. Here the fat cells are enmeshed in a loose fibrous-tissue network with a large amount of tissue fluid. Gersh and Still, in studies on the rat, showed that blood vessels and lymphatics form a rich network throughout the adipose tissue. This tissue can be distorted readily, and it slowly resumes its original shape as a result of the pressure of tissue fluid and the elasticity of the muscles or other structures beneath. Soft adipose tissue should not be looked upon as supportive, but as packing material for the body. It serves as subcutaneous insulation and as a readily available source of nutrition (Fig. 1).

At the other extreme, with many gradations of firmness, is elastic adipose tissue (Fig. 2). This is supportive tissue, and merits the attention of orthopaedic surgeons. Schaffer observed that elastic adipose tissue sometimes takes over the function of cartilage and is as resistant to pressure. In certain regions—the heels, the finger tips, the thenar and hypothenar eminences, the ischial tuberosity, and the prepatellar fat pads—there are firm deposits of fat [4], sometimes called pressure areas. In these locations, nature has adapted the available tissues to withstand sudden impacts or prolonged pressure. The architecture of the fibrous tissue is arranged to compress and bind the fat cells firmly. Elastic adipose tissue from these locations resumes its original shape as soon as the excessive pressure has been removed (Figs. 3-A and 3-B).

Tietze, in 1921, made the first detailed report on the special structure of elastic adipose tissue. In the fat pad beneath the heel, he described dense strands of fibrous tissue, enclosing circular or cone-shaped septa. The septa contained elastic fibrous tissue and closely packed fat cells. An exhaustive study of the architecture of elastic adipose tissue was made by Blechschmidt, in 1933. His material came almost entirely from the calcaneal fat pad of the human embryo, since only in early life did he find the architectural pattern undistorted. Both Tietze and Blechschmidt found fibrous-tissue strands, firmly attached to the undersurface of the calcaneus and extending to the subcutaneous tissues. These tissues were usually in the form of a letter U, with the open end of the U pointing toward the calcaneus.

In serial sections studied by Blechschmidt, the strands of fibrous tissue outlined chambers filled with fat cells. The chambers were supported by transverse and diagonal elastic-tissue fibers. There was a spiral arrangement of fibrous tissue among the fat cells, extending from the subcutaneous tissue to the calcaneus. The fat was removed from these chambers with difficulty. Firm attachments between the strands of fibrous tissue aided in resisting torsion (Fig. 4). A somewhat looser arrangement of fibrous tissue in elastic adipose tissue is seen in other parts of the body. It is thin over the palmar surface of the hand. Over the volar surface of the terminal phalanges the elastic adipose tissue is less firm than that of the heel, but is similar in structure [5]. A thick, but rather soft, elastic adipose tissue is present over the glutaeus maximus, which becomes firmer as it approaches the ischial tuberosity. Almost as firm as that of the heel is the infrapatellar fat pad.

All of these areas of elastic adipose tissue are present at birth; none develop in postnatal life under the stimulus of pressure. In portions of the body unprotected by elastic adipose tissue, which are subjected to prolonged and constant pressure, one observes pressure necrosis. If the pressure is intermittent, an adventitious bursa appears [6]. While

* Read at the Joint Meeting of The American Orthopaedic Association, The British Orthopaedic Association, and The Canadian Orthopaedic Association, Quebec, Canada, June 4, 1948.

FIG. 1

FIG. 2

Fig. 1: Subcutaneous adipose tissue (× 50), showing the loosely packed fat cells, and the meager fibrous stroma. (Stained with hematoxylin and eosin plus azan.)
Fig. 2: Elastic adipose tissue (× 30) from the heel of a child of three, showing the fat cells tightly packed by the dense fibrous stroma which is part of a "U system". (Stained with hematoxylin and eosin plus azan.)

elastic adipose tissue is constructed to withstand strain and pressure, it may be damaged by severe trauma and it shows gradual deterioration with age; under continued excessive pressure, it becomes hypertrophied at first[4]. In cadavera, the areas of elastic adipose tissue are usually firm and elastic in the young, and thinner and softer in the aged. The state of nutrition has little effect. Observers, including Batty Shaw and Wells, have found that elastic adipose tissue is spared for a long time in the nutritional demands made upon fats in the body.

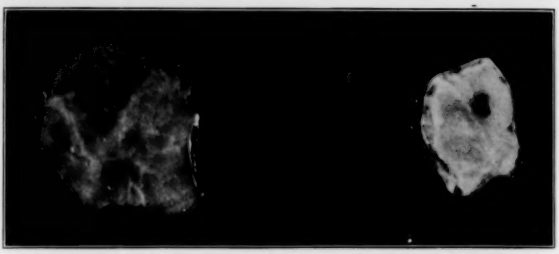

FIG. 3-A FIG. 3-B

Subcutaneous adipose tissue (Fig. 3-A) and elastic adipose tissue (Fig. 3-B) of equal bulk, compressed under a heavy glass plate. There is little change in the elastic adipose tissue. Ordinary adipose tissue is greatly distorted.

Degenerative changes with increasing age are the most constant findings in elastic adipose tissue. No regeneration has been observed. Here there is a gradual loss of collagen, a decrease in the elastic fibrous tissue, and a decrease in water content[9]. Distortion and rupture of the fibrous-tissue strands have been observed, with spilling of the fat cells (Fig. 5). In childhood and early maturity, the undersurface of the calcaneus is smooth. In the heels of elderly individuals, one usually finds evidence of loss of elasticity,—bony proliferation about the margins of the calcaneal tuberosity, roughened areas anterior to this, and bony ridges at the lateral margins of the calcaneal fat pad (Fig. 6).

The common clinical finding associated with degenerative changes in the calcaneal fat pad is soreness under the heel. This is sometimes found in the young after prolonged illness. More persistent tenderness and pain is sometimes seen after marked increase in weight, or associated with serious disturbances in the alignment of the foot. Such soreness is rarely found in children. In about 5 per cent. of adult patients seen in the clinic, tender areas were present in the posterior and inferior portions of the calcaneus. Soreness and thickening were found on the medial and lateral edges of the heel. These clinical findings are not restricted to human beings; cats and dogs, which have similar calcaneal fat pads, may show tenderness and a limp as they become old. Pathological examination shows changes similar to those found in human elastic adipose tissue.

Changes in elastic adipose tissue can be seen to a limited degree on roentgenographic examination. Lateral roentgenograms of the heel were taken to show detail in the subjacent soft tissues. The roentgenogram of the normal calcaneal fat pad shows a smooth undersurface of the calcaneus, beneath which is an area of dense fibrous tissue, about one-quarter inch thick. Beyond this is elastic adipose tissue, varying in thickness, extending to the subcutaneous tissue of the heel. In it, dense strands of fibrous tissue can be seen, extending vertically to the calcaneus. These form the "U systems", described by Tietze and by Blechschmidt. In normal individuals these strands are regular and parallel, and the chambers are similar in size. In children and in young adults who had had no injury to the feet (Fig. 7), the roentgenographic findings were normal.

In patients who complain of soreness in the heel, the roentgenograms usually show bony proliferation at the medial and lateral edges of the fat pad; this has been interpreted by the roentgenologist as periostitis. Bony irregularity about the calcaneal tuberosity is also commonly seen. In the soft tissues, there is a less dense layer of elastic adipose tissue. The fibrous strands are thinner, and are often irregular or broken in outline. They are not parallel, and the septa enclosed by the "U systems" are irregular in shape and often confluent. The sharp outlines seen in the young become increasingly distorted and blurred with age. These changes can usually be found after the age of forty (Fig. 8).

FIG. 4

FIG. 5

Fig. 4: Normal elastic adipose tissue with normal fibrous-tissue stroma from the heel of a child of four (× 60). There are blood vessels and nerves in connective-tissue stroma. (Masson stain.)

Fig. 5: Elastic adipose tissue (× 60) from the heel of a woman of sixty. The connective-tissue stroma is less dense. Breaks in the connective-tissue fibers can be seen at the lower right, as well as fatty infiltration of fibrous stroma. The fat cells are scattered. (Masson stain.)

Similar changes are also seen after marked obesity or severe trauma. In obese individuals, both young and old, often mild but easily discernible changes are seen in the soft tissues beneath the heel. A return to a normal roentgenographic appearance is rare, even after substantial reduction in weight and loss of soreness in the heel. In severe foot strain, if the mechanics of weight-bearing are restored, a normal roentgenographic picture is again found. These changes vary greatly from individual to individual, but they occur fairly constantly. In the aged, the changes increase, and no improvement is observed after prolonged avoidance of weight-bearing (Fig. 9.)

FIG. 6

Photograph of the tuberosity of the calcaneus. In specimen on the right, taken from a youth, the tuberosity and inferior surface of calcaneus are smooth. On the left, the heel of an elderly individual shows bony proliferation about the tuberosity and irregular inferior surface of calcaneus.

In severe trauma, extensive temporary changes are found in the elastic adipose tissue of the heel. Unfortunately, not many such observations with the normal side for comparison were available. After fracture of the calcaneus, a distortion of the architecture of the fat pad with flattening of the pad and rupture and irregularity of the "U systems" was usually found. With satisfactory healing of the fracture, these changes disappeared in from six to twelve months. In crushing injuries with severe comminution of the tuberosity of the calcaneus and lateral tearing and compression of the elastic adipose tissue, the changes tended to be permanent. Only partial repair occurred; a new fat pad could not be produced. In evulsion of the fat pad, observed in two patients, no change was noted in the roentgenographic picture after resuture.

FIG. 7

Roentgenogram of calcaneal fat pad in child of six. The undersurface of the calcaneus is smooth. There is a thick pad of elastic adipose tissue. Many U-shaped fibrous bands can be seen.

These changes in the elastic adipose tissue of the heel were studied histologically in a few instances, from material obtained at operations and from autopsies. Elastic adipose tissue from the heels of cadavera was also examined. In all of these, the changes observed during clinical examination and in roentgenograms were due to a loss of collagen content and to fracture and distortion of the elastic-tissue strands. The best composite picture of

FIG. 9

FIG. 8

Fig. 8: Roentgenogram of calcaneal fat pad in a woman of seventy-three. There is bony proliferation about the tuberosity. The elastic adipose tissue shows distortion of the U-shaped fibrous bands. Relatively few fibers are seen; many of these are of the "U systems" and seem to have united. The plantar vessels are calcified.

Fig. 9: Roentgenogram of calcaneal area in an obese man of thirty-six. The inferior surface of the calcaneus is roughened and shows osseous proliferation. Very few of the "U systems" can be seen.

these changes was obtained from thin sections of elastic adipose tissue, stained lightly and examined under the dissecting microscope. By this method, gross fracture and distortion of the fibrous tissue was observed. The finer changes were confirmed by fixed sections, stained to show collagen or connective-tissue fibers.

Few observations have been made of elastic adipose tissue in regions other than the heel. In a few instances, study of the infrapatellar fat pad following operations, osteoarthritis, or trauma showed changes similar to those found at the heel. An appraisal of the clinical importance of these changes in elastic adipose tissue would require a long period of study, both of clinical and of pathological material. The data obtained so far from the study of the heel permit us to state that degeneration of elastic adipose tissue is often observed with advancing years. Such degenerative changes are accompanied by stretching and tearing of the connective-tissue fibers which compress the fat cells. With these changes, and presumably as a result of them, we find pain and burning under the heel after prolonged standing and walking. Later there may be constant pain and disability. Palpation of such a heel will show tenderness in the calcaneal fat pad. Similar findings may be observed temporarily after obesity, after severe illnesses, and after trauma.

Since these changes are, for the most part, degenerative, and since therapy for degenerative lesions is almost wholly palliative, our treatment of the changes in elastic adipose tissue is symptomatic. In injuries to the calcaneal fat pad and in the milder degrees of degenerative change, a certain amount of repair may take place. In severe degeneration, however, and in crushing injuries with involvement of the blood supply, the elastic adipose tissue remains incompetent permanently. Rest and the avoidance of weight-bearing will give temporary alleviation. Injections of procaine have given only transient improvement; measures to bring about improved alignment of the foot—shoes, supports, and corrective exercises—have been followed by more lasting relief. Comfort can be obtained by forming a depression in the heel of the shoe, to avoid undue pressure on the calcaneal tuberosity. A sponge-rubber pad fitted into the heel of the shoe is another useful measure. There is no known means by which healing can be obtained in damaged elastic adipose tissue.

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THE ETIOLOGY OF TROCHANTERIC FRACTURES OF THE FEMUR

BY GEORGE N. SPEARS, M.D., AND J. T. OWEN, M.S., CLEVELAND, OHIO

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In an effort to determine the cause of fractures in the trochanteric portion of the femur in elderly people, the authors have studied 150 human femora, taken from the documented collection in the Hamann Museum. Thus the bony architecture in various age groups is correlated with the mechanics of this fracture. These facts have been substantiated by the production of trochanteric fractures in some of the bones by a specially designed machine. In addition, the mechanical forces involved have been determined from the evidence obtained in this study.

EXPERIMENTAL FINDINGS

Our material has been selected according to age, as follows: Specimens from a group of young individuals, ranging from twenty to thirty-five years, were compared with those from an older group, from sixty to eighty-five years. In addition, a group with trochanteric fractures were selected for comparison with the first two groups. Both femora, with a record of the sex, color, cause of death, and a brief history of the subject from which they had been obtained, were available for study. In the group with fractures, the unbroken mated femur was of great value.

All of the bones were macerated, according to a standard method used in the Department of Anatomy. Roentgenograms of the femora were taken, a standard technique being used to bring out the details of the architecture of the proximal end. A density gauge was pictured with each bone to judge uniformity of exposure.

Some of the bones were then fractured, by the use of a machine designed for the problem by the Case Institute of Technology (Fig. 2). This consisted of a pendulum, weighing fifty pounds, attached to a 60,000-pound Southwark-Emory Universal testing machine. The pendulum was suspended from the top of the machine, so that a dynamic force could be applied in a medial direction to the lateral portion of the upper end of the shaft of the femur. The femoral head was held in a lead form, intended to represent the acetabulum, and was padded with lead wool; the distal portion of the shaft was placed in a mold, packed with wet sand, firmly braced to the machine bed. A vertical load of from 100 to 125 pounds was applied to the head of the femur. The pendulum was then raised to various heights, and the force necessary to fracture the bone was calculated by regarding the pendulum as a free-falling body. The heights of six, nine, and twelve inches, corresponding to 300, 450, and 600 inch-pounds of energy, were found to produce the desired results. These figures were obtained by measuring the changes in vertical displacement of the center of gravity of the pendulum from its raised position to its location when in contact with the femur. Thus the bone was subjected throughout to forces simulating, to the best of the engineers' ability, those occurring in the living subject.

This mechanical treatment of the femur presented certain limitations of comparison with the living bone. For instance, the rubber pad over the steel pendulum was added in an attempt to simulate body tissue over the greater trochanter and upper portion of the shaft. The mold of wet sand and the lead acetabulum, plus the 100 pounds of vertical force, represented the ligaments and muscles attached to the femur and around the hip joint.

Repeated attempts to study the effects of torsion were unsuccessful, because of the brittle property of bone, which makes firm clamping along the shaft impractical. The only intracapsular fracture obtained with this machine resulted from incomplete fixation of

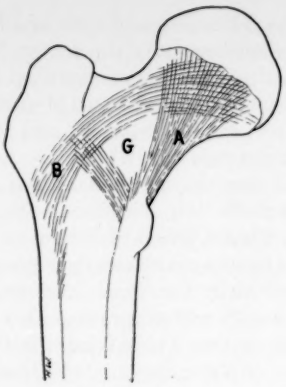

FIG. 1

Fig. 1: Diagram showing trabeculae of the upper portion of the femur.

Fig. 2: Diagram of testing machine with femur in position.

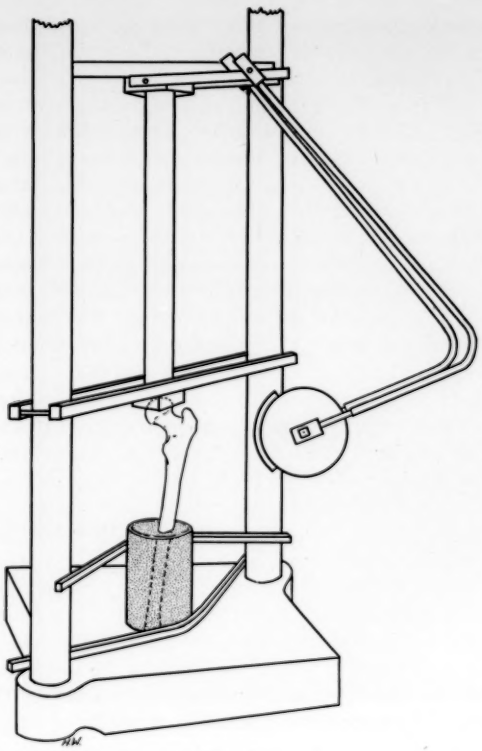

FIG. 2

the femur, so that the pendulum caused the bone to twist in the lead acetabulum and sandbox as it struck the lateral portion of the upper end of the shaft.

Finally the femora were covered with an aluminum undercoating and sprayed with "stresscoat". They were allowed to dry for twenty-four hours before forces were applied to the bones for pattern analysis. "Stresscoat" is a brittle lacquer that can be applied to the surface of an object and will crack when either static or dynamic loads are applied [2, 4]. This property of the lacquer allows it to be calibrated for analysis of qualitative and quantitative stress. The pattern of the cracks reveals the direction of the force applied to the bone; the force direction is always perpendicular to the visible cracks. Only qualitative results were considered significant, since the quantitative calculations require a modulus of elasticity and reasonable uniformity of material, neither of which was attainable in the specimens studied. After the cracks had appeared, a red etching material was applied to preserve the pattern for subsequent photography.

RESULTS

The roentgenographic studies revealed a definite pattern of trabeculae, that tended to vary with the age of the individual.

In all specimens, the area known as Ward's triangle [10] can be outlined easily (Fig. 1,*G*). The most constant trabeculae are those which form the medial portion of the shaft and extend directly into the head (Fig. 1,*A*). The curved trabeculae on the lateral aspect of the shaft (Fig. 1,*B*) form the superior portion of the femoral neck and cross the medial trabeculae to terminate in the head. On the roentgenogram, the center of the neck between these two sets of trabeculae is seen as a less opaque triangle, with the apex pointing toward the head. The base is identified as the portion parallel with the intertrochanteric-ridge pattern.

In the young adult, the entire upper end of the femur presents a gray sheen, described by Todd, caused by the abundance of mineral deposited throughout the area (Fig. 3). As

a result of senility or debility, the gray sheen is lost and the trabeculae stand out against the less opaque background. Careful examination reveals a breaking-up of the continuity of pattern, as if segments of the lamina were dissolved entirely. This is seen earliest in line *B* (Fig. 1). The lateral trabeculae are involved extensively before the medial group (Fig. 1,*A*) show noticeable involvement. Finally this column is also weakened, and the upper end of the femur becomes much less opaque to roentgen rays (Fig. 4).

The group of femora containing the trochanteric fractures showed similar areas of demineralization when compared with the unbroken mate of the pair. The fracture lines in the broken bones were found to go through this area. Then a group of femora were fractured under controlled conditions at Case Mechanics Laboratory, and roentgenograms showed the similarity of the fracture lines to those described by Cleveland, Bosworth, and Thompson for their clinical group. The femora classed as poorly mineralized always broke under dynamically applied loads of 300 inch-pounds or less. Those femora in the well-mineralized group did not break or crack until a load of 600 inch-pounds had been applied, and in some instances they did not break under the highest loads (Table I).

For further analysis of the mechanics of this fracture, another group of femora were treated with "stresscoat", and the pattern of the cracks obtained under dynamic loads was studied.

DISCUSSION

The frequency of fractures through the trochanteric region in elderly people is well known. In addition, there is evidence of demineralization in this area in these cases. This leads to the conclusion that the relative strength of the femur in the older person is less than that in a young adult. The fracture line has been shown by roentgenography to extend through the trabeculae that are thinned out. The specific weakness of the bone in this demineralized area has been ascertained by the production, under specific loads, of artificial trochanteric fractures. A study of the bones after fracture, with the use of

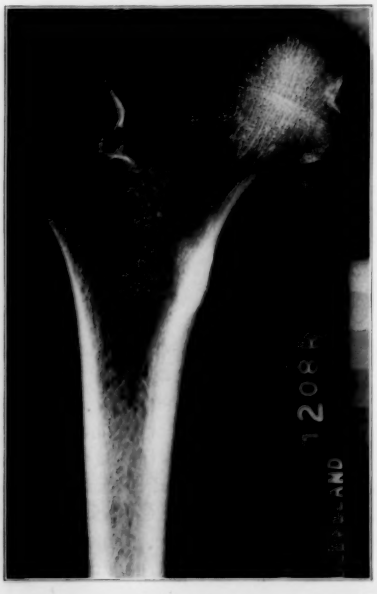

FIG. 3

Roentgenogram of femur that is well mineralized.

FIG. 4

Roentgenogram of femur that is poorly mineralized.

"stresscoat", indicates that the starting point of the fractures is probably in this same area (Fig. 1,*B* and *G*).

The trabeculae actually exist as a single tubular structure with many interlacing members crossing the medullary portion. Each trabecula must take a definite part of the total load exerted on the femur. Thus forces applied are spread throughout the neck and down into the shaft, over the pathway set up by the trabeculae[3,5,6]. Two other factors present in roentgenographic studies are those of soft-tissue absorption, which has been eliminated by this study, and the degree of calcium absorption which is visible. Lachmann and Whelan have shown that calcium loss must be in the vicinity of 20 to 40 per cent. before it is detectable by roentgenogram.

FIG. 5

Photograph of femur treated with "stresscoat".

It was seen early in this work that the degree of osteoporosis in chronic disease, even in young adults, cannot be distinguished from that occurring in senility. Consequently, only bones taken from cadavera of individuals with a history of sudden death, without known chronic disease, were used for study.

Several explanations have been offered for the strain paths shown in the "stresscoat" experiments (Fig. 5). The horizontal lines on the medial portion of the shaft and the underside of the neck may be tension cracks that occur in bending. This portion of the femur can be compared with the outer part of a simple beam. The cracks occurring around the greater trochanter at the impact point of the pendulum are indicative of the local condition only, and are not regarded as significantly related to the actual fracturing forces. However, the strain paths shown by the cracks running perpendicular to the intertrochanteric ridge indicate a tensile stress that is parallel to this ridge. All these patterns were evident in the several bones treated.

The cracks over the intertrochanteric ridge lie in the region of the bone that is shown by the roentgenographic studies to be most weak. We believe that this portion of the neck tends to become disrupted first, as determined by careful comparison of the fractured bones and of those which cracked, but did not entirely break apart. Several theories have been proposed to explain the condition, as indicated by the "stresscoat" pattern over this portion (Fig. 1,*B*). At first it was thought that this strain was evidence of Poisson's ratio[8], which is the relationship of strain in the Y direction to strain in the X direction. However, when a section of the shaft of the femur treated by "stresscoat" was subjected to static and dynamic compression, no strain paths appeared, thus showing no appreciable application of the Poisson ratio.

Another suggestion was that tensile stress might be created parallel to the intertrochanteric ridge, due to what can be called "arch action". This theory can be explained by the strain pattern that appears in a parabolic column. No evidence has been intro-

TABLE I

RELATION OF MINERALIZATION OF BONE TO LOAD REQUIRED TO PRODUCE FRACTURE

Bone No.	Degree of Mineralization	Fracturing Force (*Inch-Pounds*)			Remarks
		300	450	600	
16	Good	0	0	0	No fracture
32	Good	0	0	+	Cracked only
14	Good	0	0	+	Cracked only
10	Good	0	0	+	Complete fracture
12	Moderate	0	0	+	Cracked only
17	Moderate	0	0	+	Cracked only
27	Moderate	0	0	+	Cracked only
11	Moderate	0	0	+	Complete fracture
15	Moderate	0	0	+	Complete fracture
23	Moderate	0	0	+	Complete fracture
30	Moderate	0	0	+	Complete fracture
19	Poor	+			Complete fracture
21	Poor	+			Complete fracture
25	Poor	+			Complete fracture

duced as yet to refute this statement. Furthermore, when the fracture line is examined with this idea in mind, it appears possible that the intertrochanteric area is subjected to a tensile stress as explained by the "arch-action" theory, and that the actual break may be due to sheer. This is further substantiated, inasmuch as the edge of the cortex breaks at a 45-degree angle from the external to the internal surfaces. This plane is at 45 degrees to the apparent direction of principal stress. However, there is doubt that a material as brittle as bone will fail under sheer.

The fact that the fracture occurs in the lateral trabeculae first and then extends to the medial trabeculae is further substantiated by the behavior of this medial portion of the femur. It is shown by the "stresscoat" to be subjected to an initial tensile stress, and yet it appears to fail because of a compression-type load. This can be explained by a stress-reversal reaction, in which the arch of the neck tends to become straightened and elongated under the lateral load. Since both ends of the femur are restrained, the trochanteric portion of the medial trabeculae can fracture only by compression.

NOTE: The assistance of Carl C. Francis, M.D., of the Department of Anatomy, is gratefully acknowledged.

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THE SHORT FIRST METATARSAL

Its Incidence and Clinical Significance*

BY ROBERT I. HARRIS, M.B., AND THOMAS BEATH, M.D., TORONTO, CANADA

The importance of shortness of the first metatarsal as a cause of disability of the fore part of the foot and of the longitudinal arch has been widely discussed since 1935, when Dudley Morton, in his admirable monograph, *The Human Foot*, first advanced this thesis. His idea seemed reasonable, and orthopaedic surgeons soon found a sufficient number of patients suffering from disabilities of the fore part of the foot associated with a short first metatarsal to lead many of them to accept this as the cause of the disability. In actual fact, the problem has never been submitted to adequate study, either by Morton or by others; and there is nothing in *The Human Foot* concerning the association of the short first metatarsal with foot disabilities which might not be the result of coincidence.

Difficulties in the management of foot problems in the Canadian Army during the recent War necessitated an extensive study of these problems by the Royal Canadian Army Medical Corps. The findings of this Canadian Army Foot Survey in respect to the short first metatarsal are of considerable interest and importance, the more so since they do not support Morton's hypothesis.

Morton's Thesis

It is Morton's contention that shortness of the first metatarsal causes disturbances in the transmission of weight and thrust forces through the fore part of the foot in the following manner:

1. If the first metatarsal is shorter than the second, it carries less than its normal share of weight, since its shortness prevents its head from reaching the ground as readily as does that of the longer second metatarsal. The bulk of the weight load transmitted through the fore part of the foot is shifted from the first metatarsal to the second, or to the second and third metatarsals.

2. The altered transmission of weight is manifested by: (a) calluses beneath the heads of the second or the second and third metatarsals; and (b) roentgenographic evidence of thickening of the shaft of the second metatarsal in response to the increased stress to which it is subjected.

3. In an attempt to make the head of the first metatarsal reach the ground and bear its share of the weight, the fore part of the foot is pronated. This distorts the mid-tarsal joint and produces strain of the longitudinal arch.

Morton also contends that the same disturbances of weight distribution through the fore part of the foot occur:

1. When there is hypermobility of the first metatarsal segment as compared with the second. When this exists, weight-bearing displaces upward the head of the first metatarsal more easily than the second, which, in consequence, must transmit the greater proportion of the weight.

2. When the sesamoids of the hallux are placed more posteriorly than normal. This, in effect, is the same as a short first metatarsal, since the sesamoids provide the effective weight-bearing point of the hallux.

According to Morton, therefore, a short first metatarsal or hypermobility of the first metatarsal segment or posterior displacement of the sesamoids can be the source of foot disability, first, in the fore part of the foot, where it causes calluses beneath the

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 26, 1948.

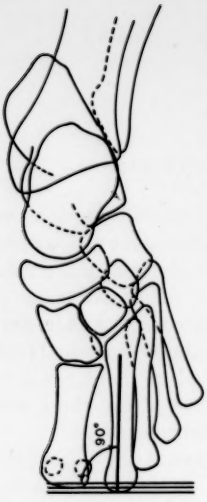

FIG. 1-A

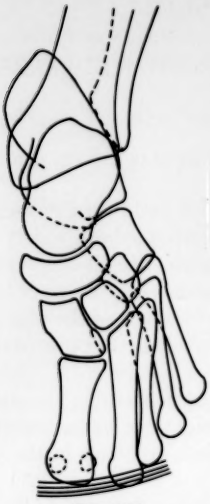

FIG. 1-B

FIGS. 1-A and 1-B

Comparison of the Canadian Army Foot Survey method of measurement with Morton's method. Shows the variation which may occur in Morton's method of measurement, dependent upon the amount of varus of the metatarsals. Tracings are from the same roentgenogram and are exactly similar. On the left, by Morton's method, the first metatarsal is shorter than the second by 1 millimeter. This measurement changes with the varus or valgus position of the metatarsals. On the right, by Survey method of measurement, the first metatarsal is shorter than the second by 6 millimeters. This measurement is not changed significantly by the position of the metatarsals.

head of the second metatarsal, falling of the transverse arch, and pronation of the fore part of the foot; and, second, in the longitudinal arch, which is subjected to undue strain by attempts to compensate for the diminished weight borne on the head of the first metatarsal. In *The Human Foot,* Morton stated that shortness of the first metatarsal is but occasionally the cause of disability, and then only in adult life. Nonetheless, it has been widely assumed that the presence of this anomaly inevitably tends to cause foot disablement, because of the disturbance in the transmission of weight and thrust stresses through the fore part of the foot. This we have found to be incorrect,—at any rate, for an unselected group of adult males, ranging in age from eighteen to thirty-five years.

CANADIAN ARMY FOOT SURVEY

The Foot Survey of the Canadian Army was designed to determine the incidence of all important foot defects among young adult males presenting themselves for army enlistment, and to assess the effect of these defects upon foot function by observation of the type and degree of disablement which developed during military training. At the enlistment center, 3,619 men were examined by precise methods. Of these, it was possible to follow 1,391 during their military training and to determine the functional capacity of their feet. From such observations, important conclusions have been drawn in respect to the alterations in function which result from foot defects and abnormalities, including shortness of the first metatarsal.

METHODS OF STUDY

Study of the short first metatarsal by the Canadian Army Foot Survey was conducted as follows:

Length of the First Metatarsal

The relation of the length of the first metatarsal to that of the second was determined by measurement from a standardized dorsiplantar roentgenogram of the foot. No other record permits accurate determination of the relative length of the first and second metatarsals. The special roentgenographic technique provided exactly comparable roentgenograms, showing all the bones of the foot with equal clarity from the posterior end of the calcaneus to the tips of the distal phalanges. Measurement of the distance from the posterior end of the calcaneus to the head of the first metatarsal and to the head of the second metatarsal gave precise information as to their relative length. This method of measurement is the most accurate, as is recognized by Morton, since it provides the

TABLE I

LENGTH OF FIRST METATARSAL AS RELATED TO LENGTH OF SECOND

Measurement of Difference (*Millimeters*)	Number of Cases
− 12	1
− 11	2
− 10	14
− 9	20
− 8	47
− 7	51
− 6	156
− 5	212
− 4	467
− 3	556
− 2	798
− 1	554
0	1,596
+ 1	463
+ 2	814
+ 3	459
+ 4	554
+ 5	194
+ 6	120
+ 7	49
+ 8	30
+ 9	4
+ 10	6
	7,167

Minus sign (−) means first metatarsal shorter than second; plus sign (+) means first metatarsal longer than second.

information which is essential,—namely, the distance between the posterior point of support of the foot (tuber calcanei) and the anterior points of support (heads of first and second metatarsals). In ordinary roentgenograms it is not feasible to make this measurement, since the posterior end of the calcaneus cannot be visualized through the superimposed shadow of the tibia. This difficulty has been overcome by the roentgenographic technique adopted for the Canadian Army Foot Survey.

The method adopted by Morton for determining the length of the first metatarsal in relation to the second (the position of the most anterior portion of the head of the first metatarsal in relation to a line tangent to the head and at right angles to the axis of the second metatarsal) is open to considerable error, depending upon the position of the metatarsals in respect to varus and valgus (Figs. 1-A and 1-B).

Distribution of Weight upon the Sole of the Foot

Since there is no accurate or simple means of measuring in pounds or kilograms the distribution of weight upon the sole of the foot, it was necessary to resort to two indirect methods of assessment,—(1) foot-printing and (2) clinical examination.

Foot-Printing

By the use of rubber mats surfaced with ridges at three different levels, it was possible to obtain footprints which recorded clearly variations in pressure between one area of the foot and another. Such mats print most where there is most pressure, and least where there is least pressure. Areas of localized increase in weight-bearing are clearly indicated by local intensification of the imprint (Fig. 6-B).

Clinical Evidence of Excess Weight-Bearing

The sole of the foot registers faithfully the weight it carries by the response of the skin to this stimulus. The greater the weight carried by a given area of skin, the thicker does its epidermis become. If weight is concentrated in a small area, the epidermal thickening is so great and so sharply defined that it becomes a callus which presses into the underlying dermis and causes pain. The skin upon the sole of the foot, therefore, becomes a record of the relative amount of weight borne by each part of the foot. Clinical observation permits us to read this record and to observe where most weight has been carried.

Functional Capacity

Of the men examined at the time of enlistment by the methods outlined, 1,391 were re-examined during their military training to observe the functional capacity of their feet. It was possible thus to correlate the findings of the enlistment examinations relating to structure with the functional performance of these feet under the stress of military training.

We have, therefore, accurate observations upon 3,619 pairs of feet, from which to determine the incidence of a short first metatarsal and of abnormal localized areas of weight-bearing (callus), and further observations upon the functional capacity of 1,391 pairs of these feet from which to determine the effect, if any, of this anomaly upon function.*

FINDINGS OF THE SURVEY IN RESPECT TO THE SHORT FIRST METATARSAL

Incidence of Short First Metatarsal

Figure 2 illustrates graphically the length of the first metatarsal relative to the second in 7,167 individual feet. (Because of frequent asymmetry, the feet have been measured and recorded separately, not in pairs.) Table I gives the data from which Figure 2 was compiled. It can be seen that:

In 2,878 feet the first metatarsal was *shorter* than the second by 1 millimeter or more.

In 2,693 feet the first metatarsal was *longer* than the second by 1 millimeter or more.

In 1,596 feet the first and second metatarsals were of *equal length* (within 1 millimeter).

These figures demonstrate that shortness of the first metatarsal is common, but so also is overlength of this bone. The most common state is equality of length between first and second metatarsals (1,596 cases or 22 per cent.). The majority of the remaining cases are within a few millimeters of equality, suggesting that this represents the normal for most feet.

If we arrange the measurements with respect to individual soldiers, we find that in 1,282 men the first metatarsals were shorter than the second; and in 2,337 men the first and second metatarsals were either of equal length or the first metatarsals were longer than the second.

Incidence of Local Excess Weight-Bearing

Study of the footprints and clinical examination of the sole of the foot revealed eighty-six and one-half pairs of feet which presented evidence of localized pressure. In the problem of the short first metatarsal, however, we are concerned only with excess pressure borne by the heads of the second or second and third, or sometimes the third and fourth metatarsals. Only thirty-five pairs of feet among the 3,619 examined showed evidence of excess pressure in these situations. In the remaining fifty-one and one-half pairs, the points of localized pressure were distributed widely in other parts of the foot.

Localized pressure under the heads of the second, third, and fourth metatarsals

* Details of the technique for the roentgenograms, the methods of measuring the length of the first and second metatarsals on the roentgenograms, and the method of obtaining footprints are omitted from this paper, since they already have been fully described [1].

was by no means limited to those feet which had short first metatarsals. Indeed, evidence of disturbed weight-bearing was nearly as frequent in feet in which the first metatarsal was equal to or longer than the second as it was in feet with short first metatarsals. The findings are summarized in Table II.

Association of Short First Metatarsal with Pes Planus

Morton's contention that shortness of the first metatarsal induces pronation of the fore part of the foot and depression of the longitudinal arch makes a study of this association important. It is possible to correlate the two factors from the data of the Foot Survey, and this has been done for several relationships. In all of these studies, there is no greater incidence of pes planus or of pronation of the foot when the first metatarsal is short than when it is long. We have been unable to find any evidence that the short first metatarsal causes pes planus, pronation of the foot, or longitudinal-arch symptoms.

Functional Capacity in Relation to Short First Metatarsal

Observation of these soldiers and study of the foot problems which developed during their training did not disclose any evidence that shortness of the first metatarsal is a cause of foot symptoms during strenuous activity. Such foot symptoms as did occur during training were attributable to other causes. This is not to say that calluses beneath the heads of the metatarsals do not exist in soldiers and do not cause symptoms. They do, but the evidence that these are due to a short first metatarsal is lacking, as indicated previously.

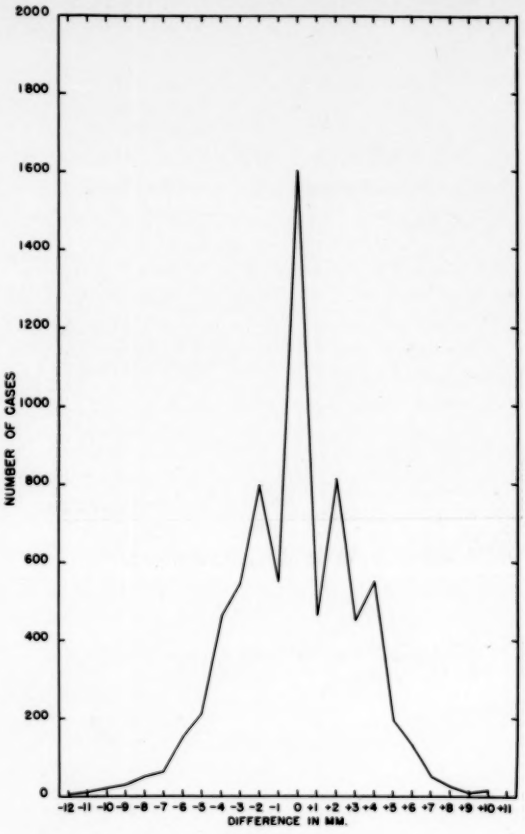

FIG. 2

Length of first metatarsal relative to length of second, obtained from measurement of standardized roentgenograms of 7,187 feet. Minus sign (−) means first metatarsal shorter than second; plus sign (+) means first longer than second. (See Table I and Figure 1-B.)

The vast majority of soldiers with measurable shortness of the first metatarsal had no symptoms related to the condition and presented no evidence of disturbance of weight distribution. The lack of symptoms when the metatarsal is short was sometimes very striking. Two examples are illustrated, one in Figures 3-A, 3-B, and 3-C and the other in Figures 4-A and 4-B. Both had very short first metatarsals and the soles of the feet were free from callus or other defects. The men were also free from symptoms.

There are many variations in the manner in which feet are used, which can act as compensatory mechanisms of considerable efficiency. One such which could easily com-

FIG. 3-A

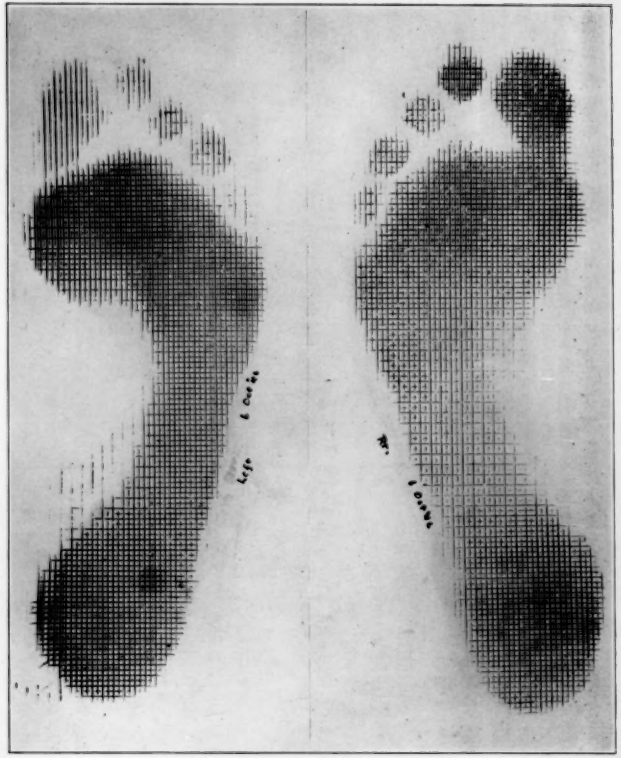

FIG. 3-B

Fig. 3-A: Roentgenograms of short first metatarsal. There was no localized pressure under metatarsal heads, no thickening of the second metatarsal, and no symptoms. A characteristic example of the large group of individuals who suffer no disability and no disturbance of function from shortness of the first metatarsal.
Figs. 3-B: Footprints of the same feet. No clinical evidence of callus is seen, and no sign of localized pressure under heads of metatarsals.

pensate for any diminution in the support normally provided by the head of the first metatarsal is increased use of the flexor hallucis muscle. The keen observer will often detect evidence of the use of the great toe in walking, and the mark of this increased use is callus on its plantar surface. If shortness of the first metatarsal really results in impairment of function from diminished weight transmitted through this segment, one would expect that the first attempt at compensation would not be pronation of the fore part of the foot, as stated by Morton, but increased use of the flexor hallucis longus. This compensatory mechanism has a high degree of efficiency, and often is used to advantage in such conditions as hypermobile flat-foot with short tendo achillis.

The remaining factors in the syndrome which are said to influence function are hypermobility of the first metatarsal segment, posterior displacement of the sesamoids, and thickening of the shaft of the second metatarsal.

Hypermobility of the First Metatarsal Segment

In spite of painstaking effort, we were unable to devise any method whereby the existence of this feature could be detected and recorded. By clinical examination we could not discover any case in which we thought the first metatarsal segment was so much more mobile than the second as to constitute a possible cause of disturbed weight-bearing. The roentgenographic evidence advanced by Morton (widening of the interspace between the first and second cuneiforms) is not pathognomic. It results merely from the chance that the central beam of the roentgenogram has passed directly through the joint space. In our opinion, hypermobility of the first metatarsal segment does not exist as a separate entity.

Posterior Displacement of the Sesamoids of the Hallux

There is considerable variation in the position of the sesamoids in relation to the anterior end of the first metatarsal. The extreme range of variation is 16 millimeters (7.5 to 23.5 millimeters), but the great bulk of the cases fall within the range of 12.5 to 16.5 millimeters.

We have been unable to determine that there is any relationship between posterior displacement of the sesamoids and excess weight borne by the heads of the second or the second and third metatarsals. This feature does not seem to be a cause of disturbed weight distribution in the fore part of the foot, any more than is shortness of the first metatarsal.

Thickening of the Shaft of the Second Metatarsal

We were unable to find any direct association between thickening of the shaft of the second metatarsal and shortness of the first metatarsal. On the other hand, when the presence of callus indicated that excess weight was borne by the second and third metatarsals, in 44.7 per cent. there was thickening of the shaft of the second metatarsal. However, many cases with thickening of the second metatarsal presented no evidence of excess weight borne by it. It may be assumed with reasonable accuracy that, when the second metatarsal bears increased weight for any reason and has done so since childhood, it will respond with increase in size; but there is no evidence that shortness of the first metatarsal is the cause of such excess weight-bearing.

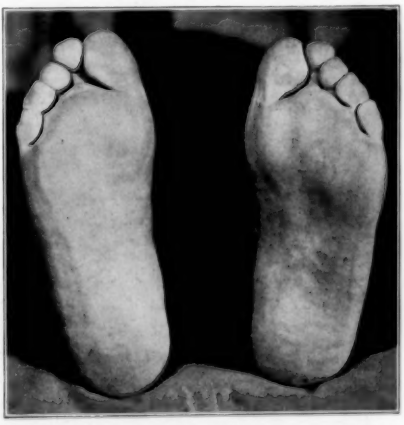

FIG. 3-C
Photograph of same feet.

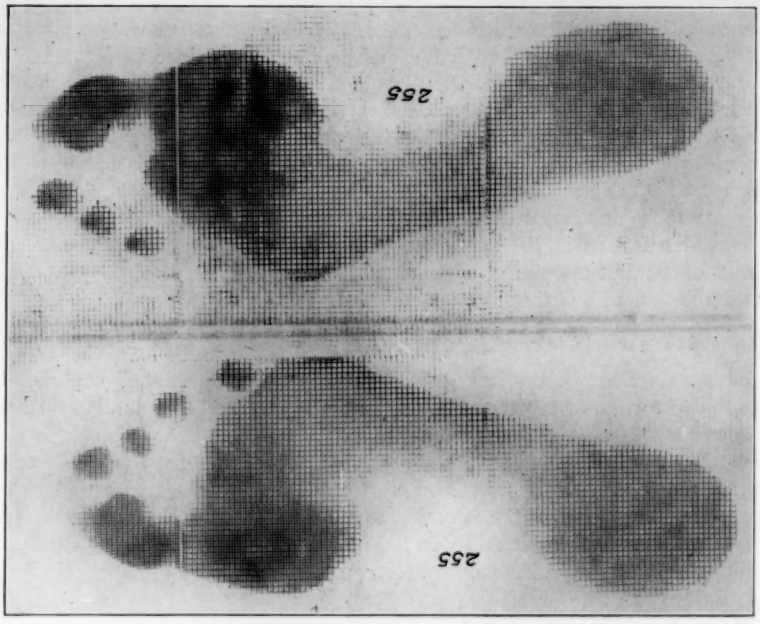

FIG. 4-B

Footprints of the same patient show no localized pressure under metatarsal heads.

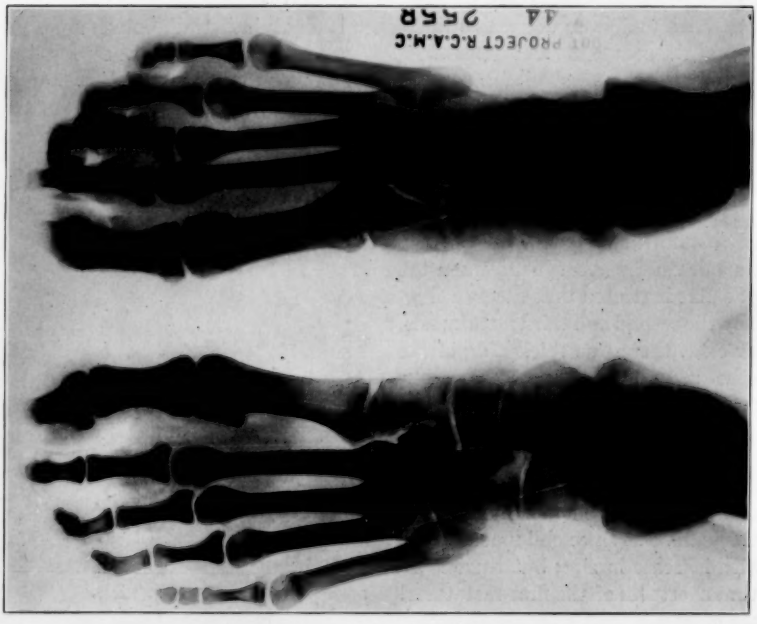

FIG. 4-A

Another example of very short first metatarsal (−8 millimeters) without accompanying disability.

FIG. 5-A

FIG. 5-B

Fig. 5-A: A case with long first metatarsal (+5 millimeters) without evidence of local excess pressure under any metatarsal head and without symptoms. Although the first metatarsal head is longer than the second, the shaft of the second is thickened.
Fig. 5-B: Footprints of the same patient show no localized pressure under any metatarsal head.

FIG. 6-A

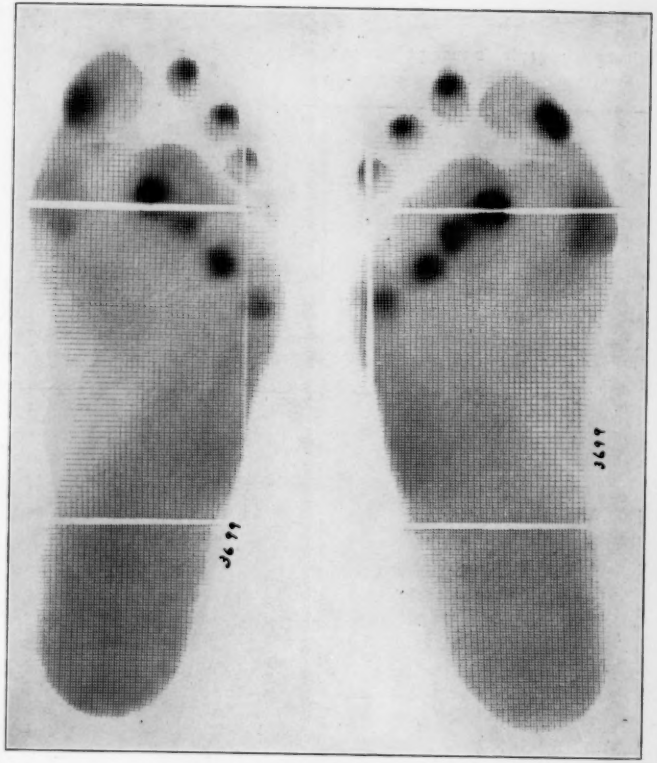

FIG. 6-B

Fig. 6-A: Splay foot; metatarsal heads are widely separated. In spite of appearance, measurement from posterior end of calcaneus to heads of metatarsals shows left first metatarsal to be 1 millimeter longer than second, and right first metatarsal to be 1 millimeter shorter than second.
Fig. 6-B: Footprints of same patient show local excess weight-bearing beneath heads of all metatarsals.

The Problem of Callus

The exact nature of callus and its causation is not easy to determine. In general terms, it is produced by pressure upon a limited area of skin. Under the influence of this local pressure, characteristic changes develop in the cornified layers of the skin,—cementing together into a homogenous mass the epithelium which normally would desquamate. As the cornified layer becomes thicker, it intensifies the local pressure and perpetuates the lesion.

The manner in which local excess of pressure is developed is obscure. In all probability several factors are involved, singly or together, of which the following play a part.

1. If the *toes* are clawed, even to a small degree, the long toe flexors no longer press the toes firmly against the ground so as to bear their share of the body weight and the thrust of the stride. This transfers more weight to the ball of the foot where, sooner or later, calluses develop under the heads of the metatarsals.

2. If the *foot* is clawed, the metatarsals are directed more steeply downward and weight is concentrated upon the metatarsal heads, because less is borne by the mid-portion of the foot.

3. The quality and the thickness of the pad of subcutaneous tissue may be altered so that weight is less widely distributed upon the skin surface.

4. When there is muscle weakness or paralysis, weight may be concentrated upon limited areas of the sole of the foot, from which it cannot be shifted because of deficient muscle power.

5. While change in position of the metatarsal heads in relation to each other, or "falling of the anterior arch", is a recognizable clinical entity, the mechanism of its production is not clear. Probably more than one factor is involved (Figs. 6-A and 6-B).

6. Certain skins perhaps form callus more readily than others.

7. There is a time factor concerned with the development of calluses. In childhood they are rarely seen; in young adult life they are rare; past middle life they are common. This might mean that it takes a long period of local excess pressure to cause callus, or that the factors which lead to the development of localized pressure appear only in the later decades of life.

DISCUSSION

The findings of the Canadian Army Foot Survey lead to the conclusion that a short first metatarsal seldom, if ever, is the cause of foot disability. Soldiers undergo the stren-

TABLE II

NUMBER OF CASES WITH EVIDENCE OF DISTURBED WEIGHT-BEARING*

	Local Excess Weight-Bearing, as Evidenced by Footprint and by Callus beneath Metatarsals			No Local Excess Weight-Bearing as Evidenced by Normal Footprint and No Callus	Total Number
	Second or Second and Third Metatarsals	Third or Third and Fourth Metatarsals	Total		
First metatarsal short by measurement	6½	7½	14 (1.1%)	1,268	1,282
First metatarsal not short by measurement	13½	7½	21 (0.9%)	2,316	2,337
Totals	20	15		3,584	3,619

* Because of frequent asymmetry, each foot is considered as one-half a case.

FIG. 7-A

FIG. 7-B

Fig. 7-A: To illustrate by analogy the mechanism whereby the metatarsal heads reach the ground and bear weight, despite differences in length. If the metatarsals were on the same transverse plane, the longest metatarsal would reach the ground first and bear the most weight.

Fig. 7-B: The metatarsals are not all on the same transverse plane, but are arched so that the central metatarsals are on a higher plane than the first and fifth. In consequence, equal weight can be borne by all metatarsal heads, even though the first is shorter than the second, provided the metatarsal arch is maintained.

uous activity of military training with no disability from short metatarsals, and react in no way differently from those who have long first metatarsals.

On the other hand, callus under the heads of the central metatarsals occurs in 0.97 per cent. of young men, and is the cause of appreciable disability. It is not specifically related to short first metatarsals, in the vast majority of which this evidence of local excess of pressure is not displayed. Also, it occurs almost as frequently in feet in which the first metatarsal is longer than the second. It probably is due to sharp concentration of pressure under a metatarsal head prominent for reasons entirely different from shortness of the first metatarsal.

Measurable shortness of the first metatarsal relative to the second does not necessarily mean that it cannot as readily reach the ground and that less weight will be transmitted through this bone. The obliquity of the metatarsals in relation to the ground means that all can share equally in weight-bearing, provided the longer metatarsals are on a higher plane than the shorter. This normally will be the case if the metatarsal arch exists. It is then possible for the second and third metatarsals to extend farther forward than the first before reaching the ground, because they are at the apex of the metatarsal arch (Figs. 7-A and 7-B).

In any case, the efficient use of the foot to support the weight of the body and to propel it in walking and running is not entirely dependent upon perfection of structure, even though this is of importance. In feet which are not perfect in their structure, compensatory mechanisms of considerable efficiency develop, which tend to offset the ill effects that might arise as the result of deviation from standard structure. In the case of the first metatarsal segment, the flexor hallucis longus, as has already been indicated, can provide the necessary supplement to function. After all, foot function is dynamic as well as static.

REFERENCES

1. HARRIS, R. I., and BEATH, THOMAS: Report 1574, Army Foot Survey. National Research Council of Canada, Ottawa, 1947.
2. MORTON, DUDLEY: The Human Foot. New York, Columbia University Press, 1935.

DISCUSSION

DR. ROBERT BINGHAM, RIVERSIDE, CALIFORNIA: Dr. Beath and Dr. Harris are to be congratulated for this excellent study, which is a distinct contribution to medical and orthopaedic knowledge in two respects:

First, by roentgenograms they have demonstrated the incidence of the short first metatarsal. Second, this study demonstrates that a great number of persons with the anatomical variation known as short first metatarsal do not have clinical symptoms, due to the compensating potentialities of the human foot. Because this study was conducted on a large group of young, physically fit men, the application of the conclusions to the human population as a whole must be considered.

Of the 3,619 persons whom they examined, slightly more than a third were studied for foot function during military training and, of these, only eighty-six are recorded as presenting symptoms. Among the thirty-five men with calluses under the middle metatarsals, only fourteen also had a short first metatarsal segment. Of this entire series of young men, therefore, only fourteen had painful feet as a result of Morton's syndrome or congenital insufficiency of the first metatarsal segment. This is too small a group upon which to base general conclusions.

In one American Army camp, we studied a group of 10,000 soldiers, in 332 of whom painful feet developed during their six months of military training. Of these, thirty-four, or slightly more than 10 per cent., had symptoms which we believed were due principally to the syndrome which Morton has described. By compensating for this functional insufficiency of the first metatarsal segment with the specific treatment recommended by Dr. Morton, we were able to return 76 per cent. of these patients to duty. In orthopaedic surgery, we have many examples of anatomical variations which frequently cause no disability, but which may, with increasing years or physical strain, produce clinical symptoms. Pes planus, an unstable lumbosacral joint, and spondylolisthesis are some of these. Insufficiency of the first metatarsal segment is, therefore, an anatomical variation which is potentially disabling.

Dr. R. Plato Schwartz, Rochester, New York: Acknowledgment of indebtedness is due to Dr. Harris and Dr. Beath for this valuable contribution. It is an exceptional instance of clinical methods of investigation applied to a mass of available material to determine the validity of a concept which was recognized on the basis of the data presented to support it.

Because of the thorough investigation leading to the conclusions reached by the authors, there would seem to be little indication for the repetition of measurements to reaffirm the absence of correlation between disabilities of the fore part of the foot and the Morton syndrome as the cause.

These conclusions are further supported by measurements of oscillographic records of the function of feet, with and without the characteristics common to the Morton syndrome.

1. Pressures recorded over the second metatarsal head, in the presence of a short first metatarsal, are found to be essentially the same as when the Morton syndrome is absent.

2. A one-eighth-inch elevation of the first metatarsal head is functionally characterized by an increase of pressure of about 20 per cent., limited to the levels of the first metatarsal head and great toe. There is no significant change induced in the pressures over any of the other four recorded levels of the foot.

3. Pronation begins with the reception of body weight by the heel. Since the first metatarsal is not functionally significant during the first 65 per cent. of the stance phase of the step, it is difficult to logically attribute effective control or prevention of pronation to a localized pressure increase at that level.

Many factors have been mentioned by Dr. Beath and Dr. Harris in reference to the cause of callus,—namely, that it does not occur with any degree of significance until the latter decades of life. They stress the point that the conditions under which the foot works and the relative mobility of the toes bring about a condition which is easily recognized as a precursor of symptoms referable to the formation of callus. One of the earliest indications, whether it be in civilian practice or in military life, of the shortcomings of function prodromal to the ultimate development of callosities, is that passive plantar flexion is usually limited earlier in the second toe than in any of the rest. This does not mean that calluses will always develop, but it is one of the first indications of functional impairment of the fore part of the foot.

A study of the inside of a shoe which has been in the closet without a shoe tree will give evidence of a depression where the plantar surface of the foot has functioned. Such depressions provoke limitation of plantar flexion of the toes. The relative fixation of the toes in dorsiflexion, in successive pairs of shoes, provokes depression of the metatarsal heads. The resulting depression of metatarsal heads becomes a major factor favoring atrophy of the plantar fat pad, either alone or in addition to callosities.

Dr. R. I. Harris (closing): We are reporting the findings of our Survey because there has seldom been such an opportunity for the mass study of foot problems. As far as we know, no such survey has been made before. We are well aware of the limitations which Dr. Bingham pointed out. It is true that we report only the findings in certain age groups. Nevertheless it was a carefully planned and precisely executed study of a considerable number of young men, the findings from which seem important.

I should like to pay tribute to my colleague, Dr. Beath, who really did all the work in the Survey. This could not have been carried out without his tremendous energy, drive, and persistence during a period of nearly two years.

ACUTE TRAUMATIC POSTERIOR DISLOCATION OF AN INTERVERTEBRAL DISC WITH PARALYSIS

BY RICHARD C. SCHNEIDER, M.D., ANN ARBOR, MICHIGAN

From the Section of Neurosurgery, Department of Surgery, University of Michigan Medical School, Ann Arbor

As the speed of automobile travel has increased and accidents at high velocities have become more common, a corresponding rise has been noted in the frequency of injuries to the spine and spinal cord. Much attention has always been given to fractures and fracture-dislocations of the spine, causing paralysis, because the diagnosis is quite obvious in the roentgenographic examination. However, very little comment has been made about acute traumatic displacement of an intervertebral disc in the causation of paraplegia. Perhaps this is due in part to the fact that the disc herniation is not apparent on the roentgenogram. At any rate, physicians have not been paying sufficient attention to this entity in the differential diagnosis of spine injuries.

Many papers have been written about compression of the spinal cord or the cauda equina by herniated discs, but in most of these cases the patients have had a history of gradual progression of symptoms for an interval of days or weeks between the initial trauma and the onset of paraplegia [3, 4, 9-15]. A few isolated cases of acute traumatic herniation of an intervertebral disc have been reported. In 1911, Middleton and Teacher presented the case of a man who had lifted a weight, heard a cracking in his back, and was unable to straighten up. Twenty hours later complete paraplegia developed with a sensory level at Poupart's ligament bilaterally, and the patient died sixteen days later. At autopsy a herniated disc was found between the twelfth thoracic and first lumbar vertebrae, which had compressed and softened the cord. Middleton and Teacher cited a similar type of case with rapid onset of paraplegia, caused by herniation of a disc at the first to second lumbar interspace, which had been reported by Kocher as early as 1896. Middleton and Teacher stated at the conclusion of their article: "The rupture of an intervertebral disc during muscular effort may prove to be a very rare injury, but it may prove to be the explanation of certain cases the nature of which has been regarded as quite obscure, or which have been ascribed to the rupture of a vessel in the cord during exertion."

In 1911, Goldthwait called attention to a case of sacro-iliac subluxation in which complete paraplegia developed a few hours after his manipulation. After numerous careful studies, he concluded that the disc at the lumbosacral joint had been extruded. He stated: ". . . the writer cannot help wondering if some of the cases of so-called transverse myelitis or cases of paraplegia without bone or neoplastic disease are not due to these features".

However, it was not until 1944 that Brooke reported another case of acute complete transverse myelitis, secondary to traumatic herniation of an ossified nucleus pulposus in the cervical region. Later in the same year Cramer and McGowan described a patient in whom immediate complete transverse myelitis had developed, due to herniation of a cervical disc; and they pointed out the part played by the nucleus pulposus in "recoil" injuries of the spinal cord.

The author believes that acute cases, whether due to recoil of the disc or to complete extrusion with compression of the cord or cauda equina, are more frequent than is realized. Three such cases, observed in the past three years, are reported here. In the first case, acute extrusion of the nucleus pulposus occurred within the thoracic region, with rapid development of paraplegia. Each of the other two patients had acute herniation of a disc in the lumbar region, with compression of the cauda equina and immediate paralysis.

CASE 1. J. W., fifteen years old, was thrown from a car on March 30, 1947. She was dazed for ten minutes and then complained of pain in the thoracic and lumbar portions of the spine with paralysis of the right leg.

When the patient arrived at a hospital, about two hours after injury, the resident physician stated that she had a flaccid paralysis of the right leg, although ankle and knee jerks could be elicited. One hour later paralysis of the left leg likewise developed. The following day a neurological examination disclosed complete areflexic paraplegia with a sensory level at the fourth thoracic dermatome. There was no plantar response to stimulation bilaterally. A diagnosis of "traumatic myelitis" was made and surgery was considered. However, it was not until April 1 that the patient was sent to University Hospital, Ann Arbor.

At the time of admission the patient exhibited an areflexic paraplegia which was complete, except for vibratory sensation at the fourth thoracic dermatome; this was still barely noticeable at the iliac crests, but not below that level. Roentgenograms of the entire spine showed only slight haziness of the inferior border of the second thoracic vertebral body, which suggested that there might be a mild compression fracture without displacement. Lumbar puncture demonstrated a complete blockage of spinal-fluid flow on jugular compression, and a specimen of fluid removed at this time exhibited a four-plus globulin reaction. Three cubic centimeters of pantopaque were injected into the subarachnoid space, and, after careful manoeuvring of the patient on a special frame on a tilt table, a complete block at the second to third thoracic interspace was demonstrated by fluoroscopy. A lead marker was applied over the second thoracic vertebra for identification purposes; a spot film was taken; and the patient was sent directly to the operating room.

About forty-eight hours after injury, laminectomy of the second and third thoracic vertebrae was performed. At this interspace the dura and cord bulged posteriorly and were unusually taut. Exploration revealed the large, completely extruded nucleus pulposus shown in Figure 1, with evidence of compression fracture of the inferior border of the second thoracic vertebra without displacement. To remove the posteriorly displaced disc without further damage to the cord, the disc had to be excised by both an extradural and a transdural approach. The cord and nerve roots were completely decompressed; the blockage to spinal fluid was relieved; and the incision was closed in layers. From operation until discharge, six weeks later, the patient showed merely a drop in her sensory level with no change in her motor status or sphincter control. A follow-up report on September 22 stated that the sensory level had further regressed to the eleventh thoracic dermatome. However, there had been no return of motor function, and she still had a bladder disturbance of neurogenic origin.

Examination of the specimen revealed a large piece of disc on which both cartilaginous and bony plates from adjacent vertebrae were still partially intact. Fracture of these vertebrae had occurred, permitting extrusion of the disc. The remainder of the fibrocartilaginous fragments had been removed piecemeal.

The fact that cartilaginous and bony plates were still adherent to both the inferior and superior surfaces of the disc bears out Edye's contention: "The body, . . . being the weaker component, gives way first under the stress of violence. The intervertebral fibro-cartilages act as buffers, as well as being the chief bond of union between the vertebrae. The vertebrae are so firmly united to one another that injury is more likely to produce fracture or dislocation than a simple tearing of ligaments." The splinting of the thoracic spine by the thoracic cage prevents mobility, and, therefore, rupture of the intervertebral disc rarely occurs. It is probable, as happened in Case 1, that fractures through the cortex of adjacent vertebrae must occur to permit extrusion of the disc. This is in contrast to the mobility in both cervical and lumbar regions, where ligaments can be more readily stretched and torn, with subsequent herniation or extrusion of the disc, without fracture of the vertebral bodies.

Case 2. On August 18, 1947, F.L.S., a graduate nurse, was found unconscious with her trunk flexed in a jackknife position, lying halfway out the door of a wrecked automobile. After she had regained consciousness, about ten minutes later, it was discovered that she was paralyzed from the waist down. She was treated symptomatically at a local hospital and then transferred to University Hospital on August 20. At the time of admission her sensory level was one segment lower than at the time of the accident. She felt the urge to void, but was unable to do so and had to be catheterized. There was hypo-aesthesia from the twelfth thoracic dermatome downward, complete areflexia, and motor loss in the thighs, legs, and feet. There was a slight flicker of movement in the hip flexors. Rectal tone was entirely lacking. Roentgenograms were negative for fracture or dislocation, with the exception of linear fractures of the transverse processes of the third lumbar vertebra bilaterally. Lumbar puncture with jugular compression was performed, and there was an abrupt rise of 150 millimeters in the spinal fluid, with a correspondingly rapid drop. Nevertheless, because of the patient's sensory level, 3 cubic centimeters of pantopaque was instilled, and on myelography a complete block was found at the first to second lumbar interspace. This persisted, although the patient was placed in an almost completely vertical head-down position. A diagnosis was made of herniated nucleus pulposus at this interspace.

About fifty hours after the injury, a laminectomy of the first and second lumbar vertebrae was performed, and a large piece of extruded disc (Fig. 2) was found. This portion of the disc was lying free in the

FIG. 1

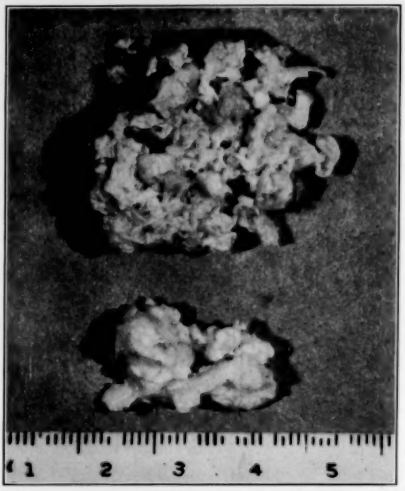

FIG. 2

In each illustration, the portion of specimen immediately above the ruler is a single piece of disc, which was found lying free in the spinal canal. The remainder of the specimen is the part of the disc which had been curetted away piecemeal.

canal, just to the left of the mid-line, causing marked compression of the dura. From the size of the hole in the ligament, it was apparent that some of the free disc might have slipped back into its original bed. The interspace was thoroughly curetted down to bone and all loose disc tissue was removed. The dura was opened and on the left side a few cauda equina roots showed a reddish-purple discoloration, but otherwise there was no abnormality. Spinal fluid flowed freely and, since the cauda equina did not appear markedly swollen, the dura was closed tightly.

Within sixty hours, the patient had a complete return of sensation, but there was no voluntary motor function and cystometric examination revealed a bladder disturbance of neurogenic origin. Seventy-two hours after operation the patient had good movement of her hamstrings and a very definite sense of fullness in her bladder. Ten days after injury she was discharged to a hospital near her home. At that time she had complete return of sensation and bladder control, but there was still complete areflexia of her lower extremities with just a slight flickering of her toes bilaterally.

In a follow-up letter on January 12, 1948, the patient stated that there was full movement of her lower extremities in all directions with slight residual weakness in the hip flexors and dorsiflexors of her feet, but that these were improving daily. Two small areas of hypo-aesthesia were present on the left thigh and leg, but these were disappearing gradually. She wears a back support, goes up and down stairs, and is able to carry on light housekeeping duties.

There is reason to believe that this patient might have recovered partial function without operation. Her neurological findings suggested that her lesion was slightly higher than the point of complete blockage of the pantopaque, as seen at fluoroscopy. However, because of the latter finding, it was deemed advisable to operate. Undoubtedly, the patient would have come to operation for severe pain at a later date, because of marked compression of the left nerve root by an extruded disc at the first to second lumbar interspace.

This case seems important because the Queckenstedt (jugular compression) test was negative, and yet there was complete blockage of the pantopaque at the site of extrusion.

CASE 3. On March 9, 1945, O. B., a soldier, aged twenty-six years, became intoxicated at a social gathering in France. Upon attempting to run upstairs, he suddenly experienced severe sharp pain in the lower portion of the back, fell down, and was unable to walk. He noted numbness in his feet and buttocks, and he was unable to void. There was no pain as a result of coughing or straining. At a forward medical installation a diagnosis of hysteria was made, and the patient was evacuated as a neuropsychiatric casualty. Seventy-two hours later, on March 12, upon admission to the Thirty-sixth General Hospital at Dijon, France, he presented the following neurological picture:

There was pain at the fourth to fifth lumbar interspace, and gentle percussion at this point greatly increased his discomfort. The patient could not stand, but in the recumbent position there was no radiation of pain into the legs on jugular compression. There was pain on straight-leg raising at 20 degrees bilaterally. Weakness was present in both right and left lower extremities, with complete paralysis of all movements of both feet. Hypo-aesthesia was present in the fourth lumbar, fifth lumbar, and first sacral dermatomes on the right. The patellar reflexes were hyperactive bilaterally, whereas both Achilles jerks were absent. A diagnosis of centrally herniated nucleus pulposus was made by Lieutenant Colonel J. E. Webster. Lumbar puncture was performed, and the spinal-fluid protein was found to be 96 milligrams per 100 cubic centimeters. Lipiodol was introduced into the spinal canal, and an invaginating defect, 1 centimeter in diameter, was noted at the fourth to fifth lumbar interspace on the left.

Early on the morning of March 13, about eighty-four hours after injury, the patient had a laminectomy (performed by Lieutenant Colonel J. E. Webster, assisted by the author) under general anaesthesia; a huge protruded disc, markedly compressing the left side of the dural sac at the fourth to fifth lumbar interspace, was found to be present. This was incised and the contents were removed piecemeal.

The patient had an average convalescence. At the time of evacuation to the United States on April 25, he had had only moderate improvement in power of his lower extremities, with the right showing further recovery than the left. No movement in any direction was evident in either foot. A loss of sensation in the sacral dermatomes remained. The right patellar and hamstring reflexes were normal. The left patellar and hamstring reflexes and both Achilles jerks were absent. Voluntary bladder control was present, with urgency and occasional incontinence. He was unable to stand.

In a follow-up letter from this patient on January 12, 1948, he stated that he was able to walk with the aid of a back brace and a lock type of brace to compensate for his foot-drop on the right. The left foot was completely normal in all movements. There was still hypo-aesthesia in the fourth lumbar, fifth lumbar, and first sacral dermatomes on the right, as well as in the saddle area. Occasionally there was hyperaesthesia in these areas and mild involuntary jerking spasms in the legs. Control of the vesical sphincter was good, but he had lack of sensation in his rectum and was always constipated.

In this case a faulty diagnosis of hysteria was originally made without a satisfactory neurological examination, a lumbar puncture with studies of the spinal-fluid dynamics, or a myelographic examination. The patient's greatest neurological deficit now is on the side opposite to the one where greatest compression of the cauda equina was visualized at operation.

DISCUSSION

Unfortunately there is still a marked tendency on the part of many surgeons to overlook completely, or ignore until too late, those signs and symptoms which are indications for surgery in injuries of the spine and spinal cord. All too frequently the general attitude is that a cord injury is an utterly hopeless problem, and it is useless to do anything about it. As a result, those individuals who might have had a chance of recovery actually do become "hopeless cases".

The early indications for surgery in spinal-cord injuries are usually given as:

1. A history of progression of neurological signs.
2. Compound fractures of the spine, particularly in those cases with spinal-fluid leaks.
3. Marked encroachment of bony fragments upon the spinal canal, as exhibited in the roentgenograms.
4. With a lumbar-puncture needle in place, evidence of complete blockage of the spinal fluid on jugular compression.

To these it is believed a fifth should be added:

5. Evidence of blockage of a column of pantopaque upon myelographic examination in those cases which, in spite of a negative Queckenstedt test, have a definite sensory level.

The first two indications listed require no discussion, but the last three should be commented upon. It should be emphasized that, at operation, 30 or 40 per cent. more damage to the vertebrae may be noted than can be visualized in the roentgenogram.

As shown in Case 2, if one relies merely upon a positive jugular-compression test as an indication that operation should be performed, extruded discs may be missed. It is obvious that this test will be negative as long as a subarachnoid space of the diameter of a No. 20 needle is still present. The validity of the test is good for that moment during which

the procedure is being performed. It is known that oedema may gradually develop in the injured cord or cauda equina hours or even a few days after this initial test has been performed; and, unless the procedure is repeated several times, a true surgical lesion may be overlooked. For this reason it is advocated that early pantopaque myelography be performed in these lesions where there is no block to jugular compression, and yet a good sensory level is present.

A word of caution is offered to those doing myelography on these individuals. In order to prevent further damage to the injured cord, the patient should be anchored securely to a board on the x-ray tilt table, with a firm supporting yolk at the shoulders and adjustable ankle supports. This enables tilting of the patient into an almost vertical head-down position, without compression of the vertebral column or the spinal cord.

It would seem unnecessary to emphasize these criteria, but only too rarely are they followed. In all of the cases reported here, operation was performed much later than it should have been, and the degree of disability has, at least theoretically, been increased proportionately. These cases should be regarded as surgical emergencies. After early accurate diagnosis, operation should be performed immediately by a competent surgeon, for the elements of the central nervous system do not, in general, withstand prolonged compression without the occurrence of irreversible anatomical changes.

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CONGENITAL POSTERIOR ANGULATION OF THE TIBIA

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Congenital anterior angulation or bowing of the tibia has attracted the interest of orthopaedic surgeons for many years, chiefly because of the severity of the deformity and the difficulties encountered in treatment. Although the deformity is rare, many writers have considered it as related to congenital pseudarthrosis. Experienced orthopaedic surgeons are aware of the likelihood of non-union following fracture or osteotomy to correct the angulation.

Congenital posterior bowing, on the other hand, has not been described adequately. While rare cases may have been observed, they have not been reported sufficiently to make this type of bowing generally known as a separate entity. Since one of the writers has treated three such cases, and has observed them sufficiently long to know the outcome, it seems important to describe them and to report the results of conservative treatment.

In the literature, practically all cases of bowing of the tibia are referred to as congenital angulation or congenital bowing, irrespective of the underlying pathological condition. Heretofore, two forms of congenital angulation have been well described and are recognized. It is the authors' purpose to add a third group, consisting essentially of posterior angulation with talipes calcaneus, and to differentiate this entity from other forms of congenital angulation.

Group I

This is the form most commonly referred to. In all of these cases there is an anterior or a forward and lateral angulation of the tibia, and pseudarthrosis eventually develops. There may or may not be a dimple over the apex of the angulation. Although it is said that talipes equinus may be present before fracture has occurred, most patients are first seen when considerable bowing is already present or after fracture with shortening of the tibia, allowing the foot to assume a position of calcaneus. The bone is usually small and sclerotic, and the medullary canal is diminished. In rare cases, however, no pathological change is readily demonstrable in the roentgenogram. The deformity is a local one, not associated with abnormality of other bones.

It is most commonly accepted that a primary defect exists in the structure of the tibia. This has been attributed to a fibrocystic lesion at the apex of the angulation (Figs. 1-A and 1-B), an associated neurofibromatosis, or a congenital deficiency or absence in the nutrient artery. Perhaps the most widely held theory of etiology is that of a defect in the germ plasm, which is a lesser manifestation of the same factor that results in congenital absence of the tibia. Freund, however, believed that the sequence of deformity and pseudarthrosis is not caused by a primary defect in the tibia, but rather that a disproportion of growth between the bone and the calf muscles causes the angulation and ultimately results in fracture and pseudarthrosis (Figs. 2-A and 2-B). His concept was similar to that of Middleton's explanation of the deformity in the next group.

Group II

The second group of congenital angulations of the tibia are those characterized by anterior bowing, associated with shortening of the calf muscles. There is a severe and markedly resistant talipes equinus. Spontaneous fracture with pseudarthrosis is not the

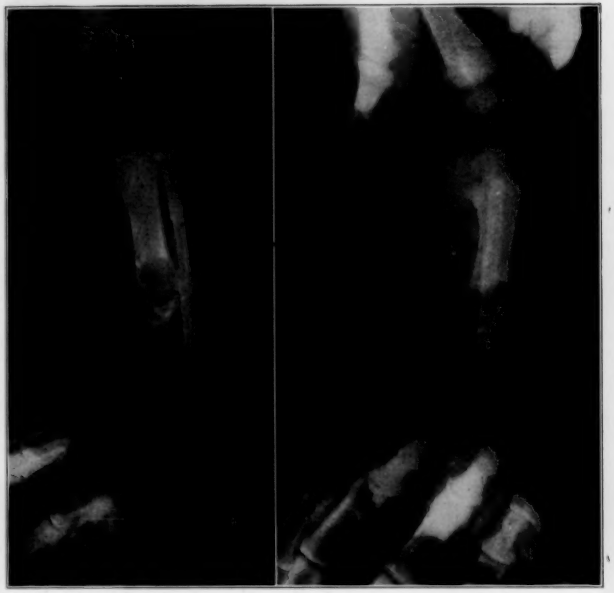

FIG. 1-A

Fig. 1-A: Group I. R. K., two months of age. Showing one type of congenital bowing with a fibrocystic lesion.

Fig. 1-B: Same patient at three years of age. Early curettage of the cyst and packing with bone chips did not prevent pseudarthrosis and severe anterior angular deformity.

The deformity was subsequently corrected and union appeared solid, four years after a dual bone graft.

FIG. 1-B

FIG. 2-A

FIG. 2-B

Fig. 2-A: Group I. M. B., at two years of age. Illustrative of another type of congenital bowing. There had been a recent fracture without known trauma. There was sclerosis of the tibia at the site of the fracture.

Fig. 2-B: At six years of age, typical pseudarthrosis was present after an unsuccessful bone-grafting operation. There was marked anterior and lateral angulation. Eventually the leg was amputated.

FIG. 3

Group II. J. S., at the age of thirteen months. There was bilateral anterior angulation of the tibia, absence of the fibula, severe equinus deformity, and developmental abnormalities in the foot.
The child is now eleven years old. One foot has been amputated; the deformity of the other foot has been corrected. He is a normally active child, and there has been no fracture of either tibia.

rule, as in cases in Group I. While the predominating deformity is that of the tibia and foot, there is usually a coexistence of other anomalies of development, such as absence of some of the bones of the foot, syndactylism, absence of the fibula, and congenital dislocation of the hip (Fig. 3). There is usually marked shortening of the entire lower extremity, mostly below the knee. The roentgenograms reveal thickening of the tibia on

FIG. 4-A

Group III. M. A. S., at eight months of age, April 6, 1941. There was severe posterior and medial bowing of the left tibia and fibula at the junction of the middle and lower thirds. The upper and lower tibial epiphyses appeared normal as compared with those on the right, although the left leg was shorter. Ossification appeared normal, except for a rather marked increase of density on the concave sides of the curves.

the concave side of the curve; the sclerosis may involve the entire thickness of the bone. A dimple is present anteriorly at the apex of the angulation. A constant finding is a very tight tendo achillis with severe talipes equinus.

Freund, Kite, and Middleton have described this group of cases in detail. Freund considered the deformity as caused by a faulty anlage of the extremity. It was Middleton's opinion that the angulation is secondary to shortening of the calf muscles, due to failure "during intrauterine life of the last stage of growth in length of the developing myocyte . . ." This would account for the fact that histologically the muscle cells were normal, but short. The muscles do not keep pace with the increase in length of the skeleton, leading to progressive functional shortening of the tendo achillis. Middleton did not believe, however, that congenital shortening of the muscle is the cause of the angulation in Group I. In many of the cases in this category the fibula is absent; this Middleton believed to be a concomitant anomaly, and not an etiological factor in tibial angulation. However, most of the patients with absence of the fibula also show tibial angulation, talipes equinus, a dimple over the apex of the curve, and shortening of the leg.

FIG. 4-B

May 27, 1948, at the age of seven years. Ossification and alignment of the tibia and fibula were essentially normal following conservative treatment. The leg had been without protection for four years.

Group III

This is the group of congenital angulations which the authors are submitting as a clinical entity, distinct from those in Group I and Group II. The cases are characterized by:

1. Posterior angulation or backward and medial bowing at the junction of the middle and lower thirds of the diaphysis of the tibia. The fibula is similarly bowed.
2. Severe talipes calcaneus.
3. Tightness of the anterior muscles of the leg and weakness of the triceps surae.
4. Presence of a dimple over the apex of the angulation.
5. Shortness of the lower extremity confined chiefly, if not entirely, to the leg, and underdevelopment of the muscles of the leg.
6. No detectable abnormality of the structure of the bone, other than a thickening of the cortex on the concave side of the curve.
7. No appreciable impairment of the upper or lower tibial epiphysis.
8. No unusual tendency to fracture.
9. Good prognosis with conservative treatment.

A review of the literature has disclosed only two cases that would fall into this category. In one typical case, reported by Freund in 1936, considerable improvement followed six months of treatment. A second case of posterior angulation of the tibia was

FIG. 5-A

FIG. 5-B

Fig. 5-A: Group III. A. L. W., at six weeks of age, September 18, 1942. There was severe posterior and medial angulation of the tibia and fibula at the junction of the middle and lower thirds. Ossification was essentially normal, except for increased density on the side of the concavity.

Fig. 5-B: April 5, 1943, at eight months of age. There was appreciable improvement in the angulation. Both epiphyses appeared normal.

reported in 1943, by Diaz Bordeu. This patient, however, showed no muscle atrophy, shortening of the extremity, or calcaneus deformity. Voshell described the case of a four-month-old infant, which fits accurately into this group. The child is still a baby. The authors are reporting three cases, followed eight years, six years, and three years, respectively.

The outstanding clinical feature of these cases is a good prognosis as a result of conservative treatment, in spite of the alarming early deformity. This at once contrasts congenital posterior bowing with the congenital anterior bowings.

The etiological factor would not appear to be a primary germ defect in the bone, since the tibia does become straight, and is approaching normal in all respects in the last roentgenograms of the cases reported here. There is no fibrocystic lesion, evidence of neurofibromatosis, or sclerosis. In fact, the early roentgenographic appearance of the bone structure is normal, except for the increased thickness of the cortex on the concave side of the curve. This is probably a manifestation of Wolff's law, with thickening or condensation of the trabeculations along the trajectory of forces to meet the stress on the curved bone. A primary congenital shortening of the anterior muscles could explain the deformity; but this is not satisfying, because the muscles are not resistant to stretching, and they continue to grow in length. The

FIG. 5-C

September 1, 1944, at two years of age. Showing continued improvement under conservative treatment.

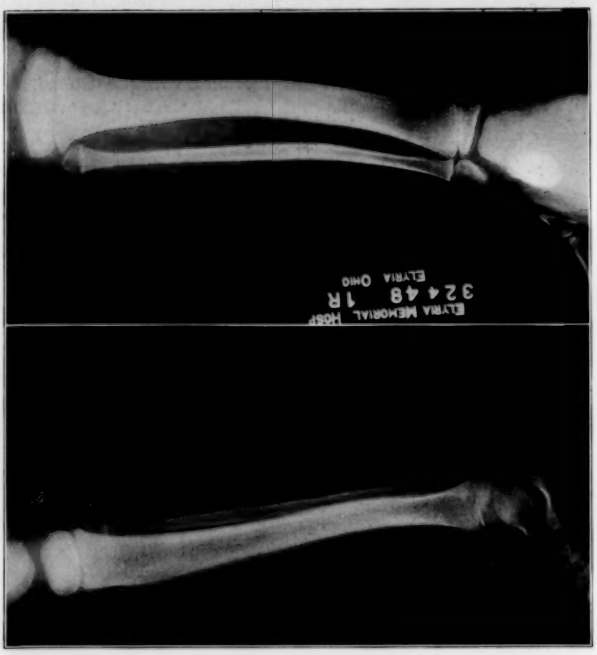

FIG. 5-E

Fig. 5-D: December 7, 1945. Patient is three years of age.
Fig. 5-E: March 24, 1948, at five and one-half years of age. Bowing had almost completely disappeared and the bony structure was approaching normal. Both epiphyses appeared normal. The leg had been without protection for eighteen months.

FIG. 5-D

response to treatment would indicate an adaptive shortening due to position, rather than the extremely resistant shortening caused by a congenital arrest in development. On the other hand, the hypothesis of a primary shortening of the anterior muscles is attractive, because this would cause only a posterior or a posterior and medial bowing. Posterior and lateral bowing has not been encountered. It is obvious that posterolateral bowing could not be caused by a shortening of muscles on the opposite side of the leg, since there are no muscles on the anteromedial side. It is unlikely that an extrinsic force, such as abnormal intra-uterine pressure, caused these deformities, because all cases are essentially the same. Perhaps the embryologist may find the answer.

The treatment of congenital posterior angulation of the tibia is conservative.

FIG. 6-A

Group III. R. R., August 3, 1945. At three weeks of age, there was severe posterior and medial angulation of the tibia and fibula with shortening of the leg, and increased density on the concave side of the curve, as in the cases of M. A. S. and A. L. W.

FIG. 6-B

April 5, 1946, at nine months of age. The tibial epiphyses on the left were comparable to those on the right. Shortening, however, was apparent. Ossification appeared normal, except for the increased density on the side of the concavity.

Osteotomy should never be performed, because of the likelihood of causing pseudarthrosis. Even osteotomy with primary bone-grafting may result in failure of union. The three cases of posterior angulation to be presented were all treated conservatively, with good results. Therapy consisted of massage and stretching of the soft tissues which hold the foot in calcaneus, and fitting the patient with a toe-to-groin brace with a leather cuff capable of being tightened posteriorly at the site of the angulation. A stop-joint was used at the ankle to prevent calcaneus. The brace was applied as early as practical—at about five months of age, before the children began weight-bearing—and was continued until the angulation had been corrected by growth, and the calcaneus deformity had been eliminated by the appearance of strength in the triceps surae.

FIG. 6-C

July 16, 1948, at three years of age. Marked improvement was evident.

Growing bone is pliant; it yields slowly to pressure or to a bending force. The brace, consisting of a doubled-back leather cuff, adjustable in tautness by means of straps and buckles between the rigid lateral uprights, exerts a continual pressure, directed toward straightening the tibia. A stop-joint at the ankle to prevent calcaneus, together with manual stretching of the soft-tissue structures anteriorly, diminishes the resistant bow-string effect of the short anterior muscles.

The patient, M. A. S., was first seen on September 17, 1940, at six weeks of age. Examination revealed severe posterior and medial angulation of the left leg, immediately above the ankle joint, which had been present since birth. There was a dimple posteriorly, over the apex of the curve. The tendo achillis was lax and the dorsiflexors of the foot were contracted, causing a severe calcaneus deformity. There were no *café au lait* spots. No treatment had been given. Roentgenograms showed severe posterior and medial angulation of the tibia and fibula at the junction of the middle and lower thirds (Fig. 4-A). The bony cortex of the tibia and fibula was thickened on the side of the concavity. Massage and stretching of the shortened soft-tissue structures were instituted to correct the calcaneus. As soon as the child began weight-bearing, at nine months of age, the brace previously described was applied. Although the epiphyses appeared normal by roentgenogram, the left lower extremity was approximately one inch shorter than the right, the shortening being all below the knee. By April 29, 1944, the condition had improved markedly, so that there was practically no limp and no gross angulation. There was good power in the triceps surae, and a normal range of motion in the ankle joint. One inch of shortening remained. The brace was then discontinued.

The child is now eight years old, and walks with only a slight limp, due to one-half inch of shortening. No gross deformity is detectable. She has excellent muscle strength in the triceps surae, and a normal range of motion in the ankle joint. Roentgenograms show no posterior angulation and very slight lateral angulation of the tibia and fibula (Fig. 4-B). The bone architecture and the epiphyses appear normal.

The patient, A. L. W., had been born with an angulation of the right leg, for which a plaster-of-Paris cast had been applied by a local physician, shortly after birth. When the patient was first seen on September 4, 1942, at four weeks of age, there was a severe posterior and medial angulation of the tibia and fibula at the junction of the lower and middle thirds. A dimple appeared in the skin over the apex of the angulation posteriorly. The foot was in severe calcaneus. The tendo achillis was lax, and the dorsiflexors of the foot were contracted. There were no *café au lait* spots. Roentgenograms, obtained on September 18, confirmed the angulation (Fig. 5-A). There was no definite abnormality of the bone structure, although the bone density

on the concavity of the curve was increased. The plaster immobilization started by the family physician was discontinued, and the patient was treated conservatively and kept under observation.

At five months of age, a toe-to-groin brace was fitted to the right lower extremity, with a leather support posteriorly at the site of the angulation. The child began walking at fourteen months of age. Gradually the deformity of the leg and the calcaneus deformity decreased (Figs. 5-B, 5-C, and 5-D). By November 1, 1946, there was only moderate calcaneus, good power in the triceps surae, and only slight angulation of the tibia. The brace was discontinued at that time. The shortening of the extremity was reduced to one inch. It should be noted that the lower tibial epiphysis did not appear on the right until April 1943.

Since November 1946, the patient has been quite well. She is now six years old, and walks with only a slight limp due chiefly to weakness of the Achilles group of muscles. There are one and one-fourth inches of shortening of the extremity, but no gross angulation. The roentgenograms of the right tibia and fibula show mild medial bowing, and practically no posterior bowing (Fig. 5-E). The bone architecture and the epiphyses appear normal.

The patient, R. R., was first seen on August 3, 1945, at three weeks of age. The baby had been born with severe bowing of the left leg, just above the ankle. He had had no treatment. Examination showed severe posterior angulation (Fig. 6-A), a dimple in the skin over the apex of the angulation posteriorly, and a severe calcaneus deformity. The tendo achillis was lax, and the dorsiflexors were tight. The left tibia and fibula were short in comparison with those of the right leg. There were no *café au lait* spots. No definite defect was noted in the bone architecture, although there was increased density of the tibia on the side of the concavity. The only treatment given initially was massage and stretching of the tight dorsal structures. At the age of nine months, when the child began to bear weight (Fig. 6-B), he was fitted with the brace and a reverse stop-lock. He learned to walk quite well with the brace, and he is still wearing this type, at the age of three years. There has been steady, gradual improvement in the angulation, and also in the calcaneus deformity. There is one inch of shortening of the left lower extremity, all below the knee. Good power is present in the triceps surae, and a normal range of motion in the ankle joint. Roentgenograms show only moderate angulation (Fig. 6-C). The epiphyses appear normal.

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CLOSED DRAINAGE OF THE KNEE JOINT FOLLOWING ARTHROTOMY

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Postoperative effusion of the knee joint is a frequent sequela of arthrotomy. It is distressing to the patient and of concern to the surgeon, for it is painful and interferes with physiological healing. Arthrotomy, of necessity, adds trauma to synovial structures which are often acutely or chronically irritated. The extensive areas of synovial membrane

respond by effusion into the joint space, with resultant swelling and increase of intra-articular pressure. The synovial membrane and capsule become tense and congested. The presence of effusion indicates the direction of the flow of lymph from the joint synovial membrane and capsule into the joint cavity. The egress of joint fluid into the lymphatics and capillaries is temporarily halted. Repeated aspiration as a means of decompression of the distended joint is often resorted to.

Many surgeons have found that non-suture or very loose suturing of the synovial membrane at the site of incision permits drainage of the effusion into the extracapsular or subcutaneous tissues, thereby preventing joint tension. This has the disadvantage of producing a "pool" of synovial fluid along the line of suture, thus interfering with early, firm healing.

A simpler means of permitting continuous drainage of the knee-joint cavity is presented here. A drainage tract is established from the apex of the suprapatellar pouch to the deep muscle planes of the thigh by penetrating the synovial membrane and capsular folds with a blunt forceps; the forceps is introduced closed, and then opened before withdrawal. The double curve of a medium-sized uterine packing forceps has been found to be ideal for this purpose. It can be introduced through any type of incision, and is long enough to reach well beyond the joint cavity. The drainage tract in this position permits escape of the joint fluid into an extensive intermuscular plane which is rich in lymphatics. It also prevents the pooling of joint fluid along suture lines. Early joint movement, active and passive, produces a "milking" effect and prevents sealing-off of the drainage tract.

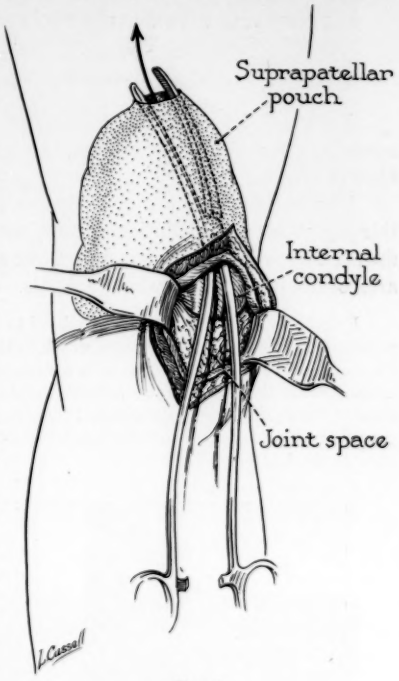

FIG. 1

Method of puncture in the suprapatellar pouch by introduction of packing forceps through incision.

Voluntary use of the extensor muscles of the knee, which is so important, is facilitated, reducing quadriceps atrophy to a minimum.

The observations of Bauer, Short, and Bennett[1] show conclusively that the larger protein molecules, especially albumin, are absorbed through the lymphatic system rather than by capillaries. This observation explains in great part the favorable course which usually follows muscle-plane drainage of postoperative effusion of the knee joint. Similar synovial drainage of other joints is occasionally indicated.

The use of this technique of drainage has almost eliminated postoperative effusion following arthrotomy of the knee joint; and postoperative pain and disability have been materially reduced.

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EVOLUTION OF METAPHYSEAL FIBROUS DEFECTS

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Localized defects in the metaphyses of long bones have been described as "cyst-like areas"[4], "non-osteogenic fibroma"[2], "metaphyseal fibrous defects"[1], and "monostotic fibrous dysplasia"[3].

The authors had the opportunity of following by roentgenograms, for a period of thirteen years, the evolution of such metaphyseal defects. This case is unusual in that, during the period of observation, three such defects appeared and regressed in the same area of the upper humeral metaphysis.

R. B., a two-year-old boy, was admitted to the Department of Orthopaedic Surgery of the State University of Iowa Hospitals on November 22, 1934, because of a curvature of the spine, present since birth. Physical examination and roentgenograms revealed a left convex thoracic scoliosis, due to congenital wedging of the third to the sixth thoracic vertebrae, and absence of the fifth rib on the left. Roentgenograms of the spine at the time of admission included the right humerus, which appeared normal (Fig. 1-A). Roentgenograms were taken at frequent intervals to follow the course of the scoliosis, and many of them included a view of the right humerus.

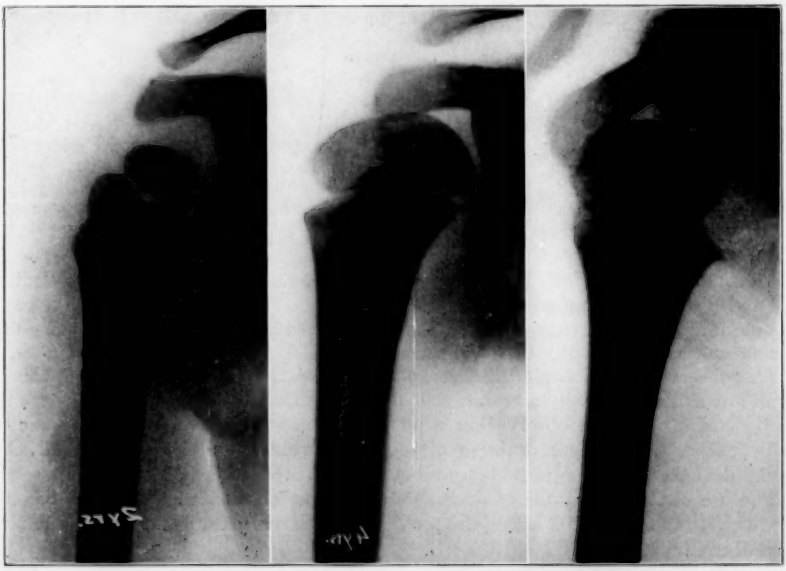

FIG. 1-A FIG. 1-B FIG. 1-C

Fig. 1-A: In roentgenogram taken at two years of age, right humerus appears to be normal.
Fig. 1-B: At four years of age, a small metaphyseal defect may be seen.
Fig. 1-C: At five years of age, because of growth of the bone, the metaphyseal defect has traveled away from the epiphysis. It is outlined by sclerotic bone.
Fig. 1-D: At five and one-half years of age, the first metaphyseal defect is still apparent, farther down the shaft. A second metaphyseal defect is seen, arising in the same location as the first.
Fig. 1-E: At six years of age, the first metaphyseal defect, which is in the humeral shaft, is becoming smaller; the second one, still in the metaphysis, has enlarged.
Fig. 1-F: At six and one-half years of age, the first metaphyseal defect is very small and is located close to the center of the humeral shaft. The second defect has enlarged and its borders have become sclerotic.

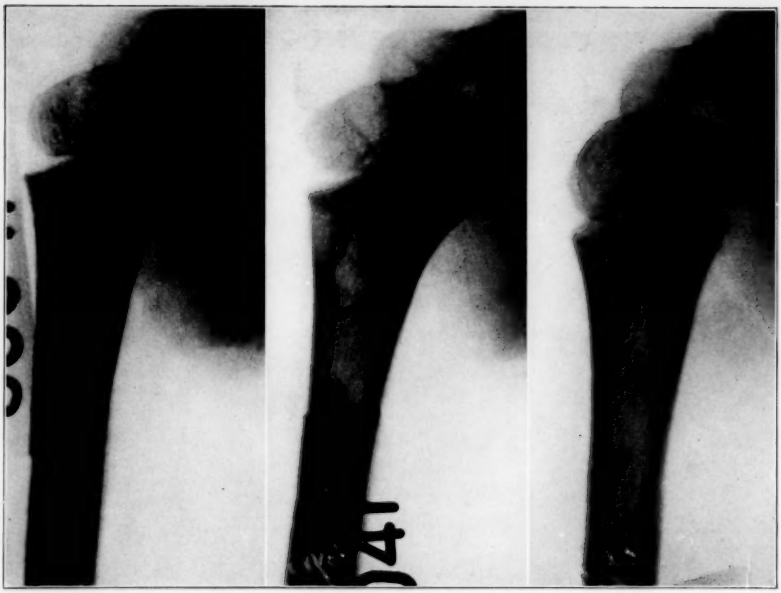

FIG. 1-D FIG. 1-E FIG. 1-F

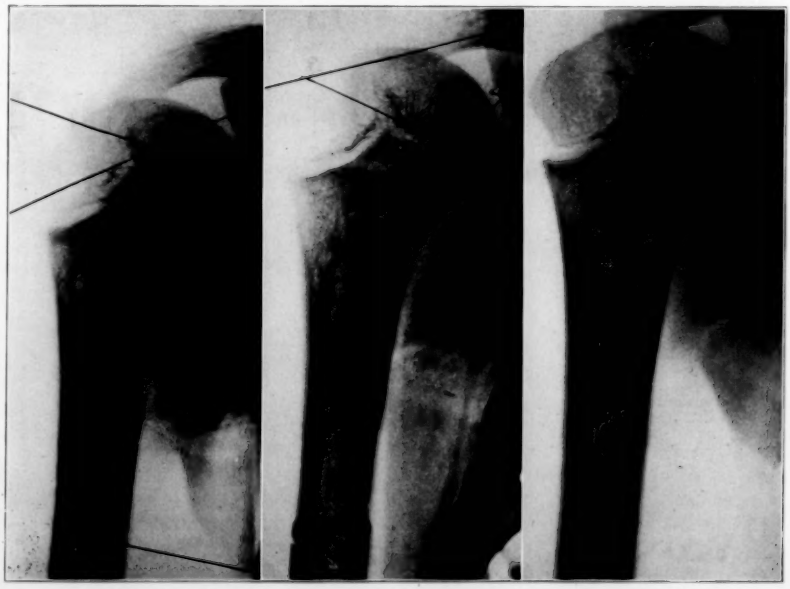

FIG. 1-G FIG. 1-H FIG. 1-I

Figs. 1-G and 1-H: In roentgenograms taken at seven and seven and one-half years of age, respectively, the first metaphyseal defect is disappearing, while the second lesion has traveled away from the epiphysis.

Fig. 1-I: At eight and one-half years of age, the first metaphyseal defect has completely disappeared. The second defect remains large.

FIG. 1-J FIG. 1-K FIG. 1-L FIG. 1-M FIG. 1-N

Fig. 1-J: At nine years of age, bone trabeculae are partially filling the second metaphyseal defect, which is still large and has sclerotic walls. A third metaphyseal defect may be seen, arising from the same site as the previous two.

Fig. 1-K: At nine and one-half years of age, the second metaphyseal defect is still apparent. The third defect is very small and is already becoming obliterated.

Figs. 1-L and 1-M: Roentgenograms taken at ten and eleven years of age show the third metaphyseal defect to be completely absent. The second lesion is gradually disappearing.

Fig. 1-N: At thirteen years of age, no lesions are to be seen and the humerus appears normal.

In 1936, when the boy was four years old, a small, well-rounded area of decreased density was noted in the upper humeral metaphysis (Fig. 1-B). In subsequent roentgenograms this lesion was seen to be enlarged, elongated in the axis of the shaft, and to have traveled away from the epiphysis with the growth of the bone. As it did so, its borders appeared sclerotic (Fig. 1-C). Later, its center became more dense; and, four years after it was first detected, this lesion had completely disappeared (Fig. 1-I). Meanwhile, when the child was five and one-half years old, a similar area of translucence was noted, beginning in the same location as the first (Fig. 1-D). This second defect became enlarged to a greater degree than the first. As before, its borders became sclerotic; later new-bone trabeculae filled in the defect; and by the time the boy was thirteen years of age, this lesion had disappeared (Fig. 1-N).

In Figure 1-J a third lesion may be seen, originating at the same site as the other two. The duration of this last metaphyseal defect was shorter, as it was no longer seen one year later (Fig. 1-L). Roentgenograms taken up to the time the patient was sixteen years of age failed to show any new lesions.

At no time did the patient have complaints referable to his arm, nor was there any history of trauma to the region. He had no *café au lait* spots, and no neurofibromata were found on physical examination. Because of the obvious benignity of these defects, no treatment was instituted.

Biopsy of the lesions was not done. However, the roentgenographic features are identical with those found in many metaphyseal defects seen in this Hospital which, at biopsy examination, were found to be filled with fibrous tissue. In some instances this fibrous tissue contained foam cells, small giant cells, and new-bone formation. Clinical symptoms are frequently absent. Jaffe and Lichtenstein, Hatcher, and Schlumberger have all described similar lesions, with correlation of the roentgenographic and pathological findings. There is no reason to doubt that the defects in the case presented belong to the same category.

The three metaphyseal defects in this case all appeared in the same area of the humerus. This indicates that they were due to a localized, intermittent disturbance in the process of ossification, as Hatcher contended. Each of the defects followed a similar course, and, as their borders became sclerotic, they migrated toward the diaphysis, finally disappearing in a period of from one to seven and one-half years. The natural course and the fact that they all originated from the same area would appear to be strong arguments against Jaffe and Lichtenstein's belief that they represent benign tumors formed from marrow connective tissue.

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EXTERNAL SKELETAL FIXATION IN THE TREATMENT OF FRACTURES OF THE TIBIA *

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The work covered by this review was done largely on the Orthopaedic Service of the Vancouver General Hospital. Many factors have been responsible for the large number of cases treated with external skeletal fixation. Apart from the fact that external fixation has a definite place in orthopaedic and traumatic surgery, its use has shortened the patients' stay in the Hospital and thus aided the universal shortage of hospital beds.

Steinmann pins and plaster in the treatment of fractures of the long bones had been used in Vancouver General Hospital for a number of years prior to 1942, with satisfactory results. Although this method was not employed on all fractures, we had sufficient experience to appreciate its efficiency and usefulness, as well as the possible complications.

In June 1942, we commenced using the external skeletal-fixation equipment devised by Roger Anderson. This paper is a review of our experience with this method of treatment. From June 1942 until the present time, external skeletal fixation has been used in over 950 fractures and orthopaedic conditions. In this series almost 4,800 pins have been inserted†.

Particularly on the coast of British Columbia, post-traumatic arthritis has been prevalent. This problem had been encountered during all types of treatment of a great many fractures, and our feeling was that the incidence of arthritis might be lessened if the joints could be kept mobile instead of being fixed for a prolonged time. A comparative statistical review, for this and other areas, of the period of fixation required for the solid union of fractures is not available, but it is our impression that union in this area is a little slower than the average, regardless of the method by which the fracture is treated.

A total of 237 tibiae have been treated by this method. These include fractures of all parts of the bone, in which our experience has shown that external skeletal fixation is an efficient method of treatment.

The method of inserting the pins has varied only slightly. Practically all of the pins have been inserted with a hand chuck. This may be considered a slow and antiquated method, but the author has always been able to insert the pin in the desired position without too much difficulty. By this procedure there is much less danger of thermal necrosis, and, as far as I have been able to determine, no case of ring sequestra has resulted from this cause.

The placement of the pins is very important; the more obtuse the angle of the pins in each unit, the better the fixation in the bone and the less the possibility of the pins becoming loose. When this has been difficult on account of the position of the fracture, an extra pin has been added to prevent side slipping. No complications have resulted from the insertion of extra pins, and the motto has been: " 'Tis better to add a pin than have one too few". With a short upper fragment, into which the upper pin cannot be placed obliquely, the pin may become loosened and allow some side motion of the bone. An extra half-pin inserted at a wide angle, probably almost anteroposterior, but possibly at a right angle, to the shaft, will give added fixation.

In the great majority of fractures of the middle of the shaft, the proximal and the distal pins have been through-and-through,—that is, the proximal pin in the proximal fragment and the distal pin in the distal fragment. The other two have been half-pins and, whenever an extra pin has had to be added, it has been a half-pin.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1948.

† Since the compilation of the statistics for this review, an additional twenty tibiae have been pinned. Approximately 300 additional pins have been inserted in fifty-seven fractures of all types.

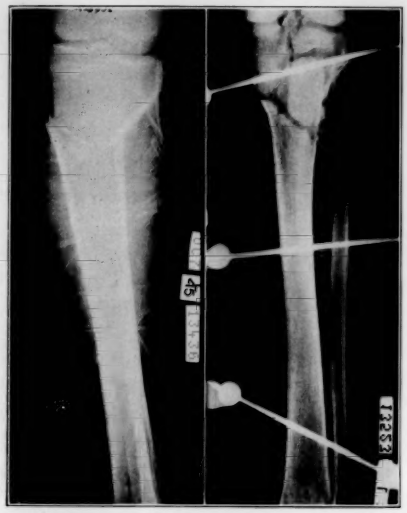

FIG. 1-A
October 7, 1945

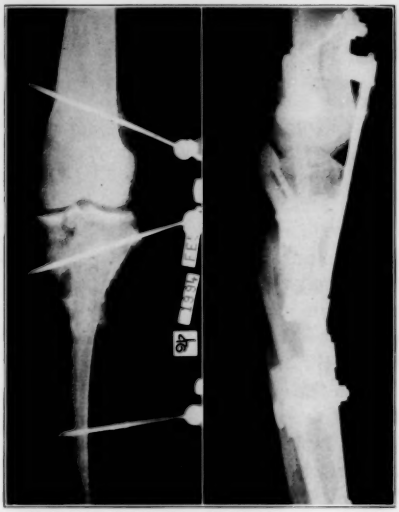

FIG. 1-B
October 9, 1945

FIG. 1-C
February 2, 1946

Figs. 1-A and 1-B: Case 119. Showing a severely comminuted fracture of the left leg; a compound, comminuted fracture of the right leg was also present. The patient's general condition contra-indicated any attempt to obtain a perfect reduction, and it was thought unwise to attempt to correct the posterior angulation by any further manipulation.

Fig. 1-C: Union had occurred at sixteen weeks.

Fig. 1-D: The result two years later.

FIG. 1-D
January 2, 1948

Originally, we treated almost all fractures, except those of the femoral neck, as emergencies. At the present time, a great many of the fractures, with the exception of those which are compound or complicated, have been treated as elective cases, and adequate general and local preparation has been given prior to the reduction and fixation.

The cases to be illustrated are those in which, with two exceptions, external skeletal fixation alone has been used. It had been felt that this discussion should not be complicated by the presentation of cases in which both internal and external fixation had been used. In a certain number of cases where open reduction has been indicated, we have used a combined method of fixation, and a combination of internal fixation with screws or nuts and bolts, as well as the pins and external bars.

The proportion of patients upon whom we have been doing a combination of open reduction and pin fixation has been increasing, but internal fixation has not necessarily been employed in all of these cases.

In the simple fractures, the pins are inserted after the usual preparation and with rigid technique, usually with an assistant putting traction on the foot. The importance

of traction during the insertion of the pins is that, if there has been much shortening, there will not be a variation in the skin tension after the fracture has been reduced.

After the pins have been inserted, small zephiran-soaked gauze dressings are spiked over the pins and held with sterile sheet wadding, and often a compression bandage is applied from the toes to below the knee. The clamps and bars are attached to the units and then the connecting bars are added. Experience has shown that no attempt should be made to look at the fracture with the fluoroscope without putting the limb in the reduction frame. After the leg has been fixed in the frame, the connecting bars are released and the fracture is inspected. The room is darkened as soon as the dressings have been applied, so that the operator's eyes may become adapted to the dark in preparation for fluoroscopy. No attempt is made to reduce the fracture under direct vision. It is inspected only with a minimum of exposure. When reduction is satisfactory, the connecting bars are firmly fixed, and the leg is removed from the frame. It is important that the knee and the ankle be put through a full range of motion before the patient leaves the operating room.

In the care of compound fractures, it has been our plan to do a thorough cleansing of the entire leg and adequate preparation of the skin. The compound wound, if possible, is blocked off with a dressing, bandaged in position after the cleansing. The pins are then inserted, the dressing is carried out as previously described, and the units are completed. The compound wound is then debrided; if possible and if it is considered advisable, the wound is closed primarily without drainage. Few patients have had delayed primary closure, the great majority with compound fractures having been admitted within a short time of the injury and having been treated within a few hours.

The after-care has been largely that of "judicious neglect" as far as the pins are concerned. The dressings have been changed only when absolutely necessary, and then only by the surgeon. Active knee, ankle, and foot movements are required. Ambulation with crutches is started the day after fixation if at all possible, and the patients are sent home.

In none of the patients has early full weight-bearing been encouraged. We have often suggested that the patient wear a shoe and start putting the foot to the ground with some weight-bearing.

Routine roentgenograms are taken before discharge from the Hospital and at ap-

FIG. 2-A
October 7, 1945

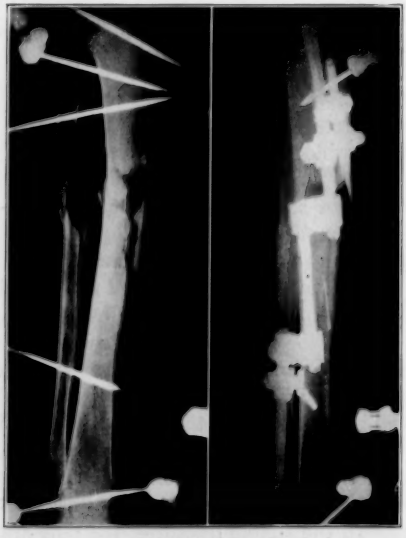

FIG. 2-B
November 19, 1945

Fig. 2-C
April 25, 1946

Fig. 2-D
April 25, 1946

Fig. 2-E
January 2, 1948

Fig. 2-A: Case 120. The right leg of the patient in Case 119 sustained a badly compounded fracture with loss of a large fragment.
Fig. 2-B: The wound was closed over the fracture, but it was not possible to appose the margins throughout. This was done by a secondary closure.
Fig. 2-C: At the end of twenty-eight weeks, the bones had united.
Fig. 2-D: An oblique view shows the apparent difference in the "filling in" of the gap.
Fig. 2-E: Two years later the patient, an eighty-year-old man, was able to walk several miles without difficulty.

FIG. 3-A
March 3, 1946

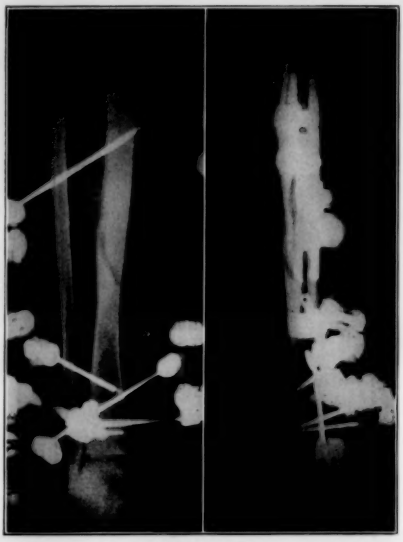

FIG. 3-B
March 5, 1946

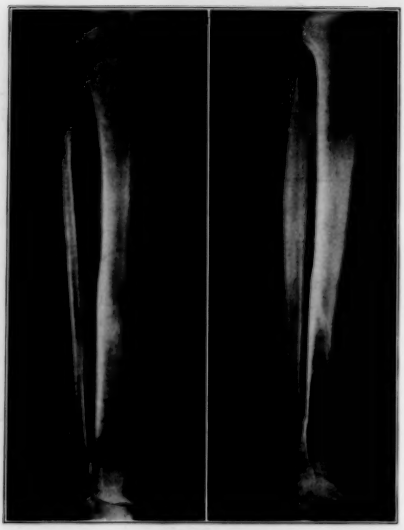

FIG. 3-C
January 2, 1948

Fig. 3-A: Case 142. This patient had a skiing accident.

Fig. 3-B: Roentgenograms taken after reduction demonstrate the use of extra half-pins in the short distal fragment below the spiral fracture.

Fig. 3-C: Shows the result almost two years later.

proximately monthly intervals thereafter. If there is a tendency to absorption and the appearance of over-extension, the connecting bars are loosened and then tightened. If the roentgenograms look satisfactory at the end of ten to fifteen weeks, the connecting bars are released and the fracture is tested clinically. If there is still a slight amount of spring at the fracture site, the connecting bars are again fastened; and, if there are no contra-indications, the patient may be advised to discard the crutches and have full weight-bearing with the pins still in position.

Representative cases demonstrate the various types of fractures, before and after operation, with x-rays of the end results.

Table I summarizes the work covered by this review. There have been only two instances of non-union among the cases of simple fracture. One patient (Case 139) had fractures of the ulna, the pelvis including the sacrum, and the tibia; the fracture of the tibia included the ankle as well as the shaft. The second non-union occurred in a patient (Case 161) who had long-standing disability of the leg, resulting from poliomyelitis. He had been struck across the back of the leg by some rolling logs, with a resulting large hematoma of the calf and with fractures of the ankle as well as of the shaft. Union took place in the

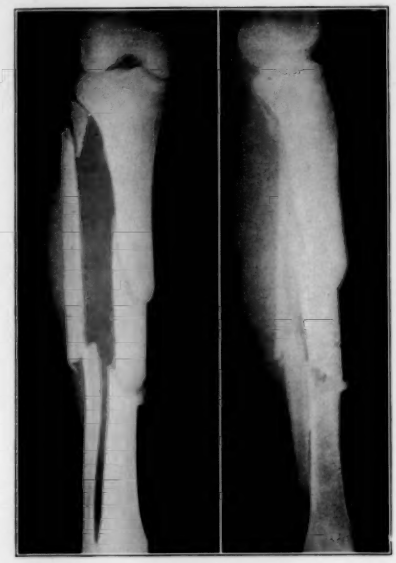

FIG. 4-A
September 28, 1945

FIG. 4-B
October 18, 1945

Fig. 4-A: Case 121. Showing a very severely comminuted but not compounded fracture.

Fig. 4-B: Demonstrating the possibilities of this method, although the technical result is not perfect.

Fig. 4-C: Showing the appearance of the leg almost two and one-half years later.

FIG. 4-C
January 2, 1948

ankle in ten weeks. After bone-grafting of the shaft, union occurred in twenty-eight weeks, but there was some necrosis of the skin over the operative area.

Early bone-grafting was done in four cases, including Case 212 (Figs. 5-A and 5-B). In Case 168, a pin clamp had broken a month after the original pinning and the fracture had become badly displaced. It was thought advisable to remove the pins, allow the pin site to heal, and then to do an open reduction and bone-grafting with re-pinning.

Minor local skin irritation about the pins occurred in about 5 per cent. of the patients. In none of these was there any definite infection or bone involvement. The areas healed almost immediately and the pins were removed; in most of them, healing was complete at the time the dressings were removed, in one week.

The second classification of skin difficulty was present in those who had definite infection about the pins, but without infection of the bone. Five patients required hospitalization for a few days on this account.

FIG. 5-A
May 26, 1947

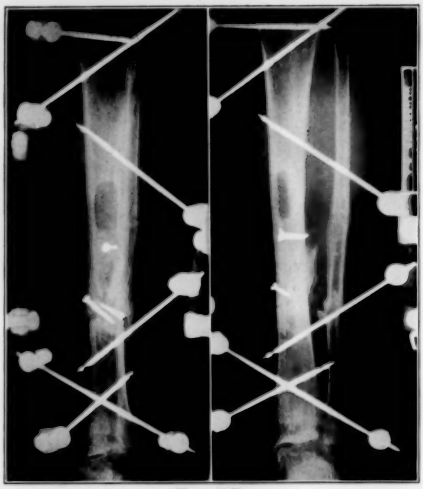

FIG. 5-B
December 23, 1947

Fig. 5-A: Case 212. A logger, who had been struck by a falling log, was admitted four days after the injury. Roentgenograms show the tremendous swelling and large bleb formation. The fracture was not compound, but there was some loss of sensation and movement, thought to be the result of the severe contusion with swelling. Any immediate interference was contra-indicated. It was three and one-half weeks before the skin was in satisfactory condition to proceed with fixation.

Fig. 5-B: An extra half-pin was placed in each fragment for firmer fixation. This case is an example of early bone-grafting in fracture of the tibia, with external skeletal fixation. Roentgenograms show the appearance twenty-eight weeks after grafting; the loss of sensation and movement is now felt to have been due to ischaemia, which developed prior to our seeing the patient.

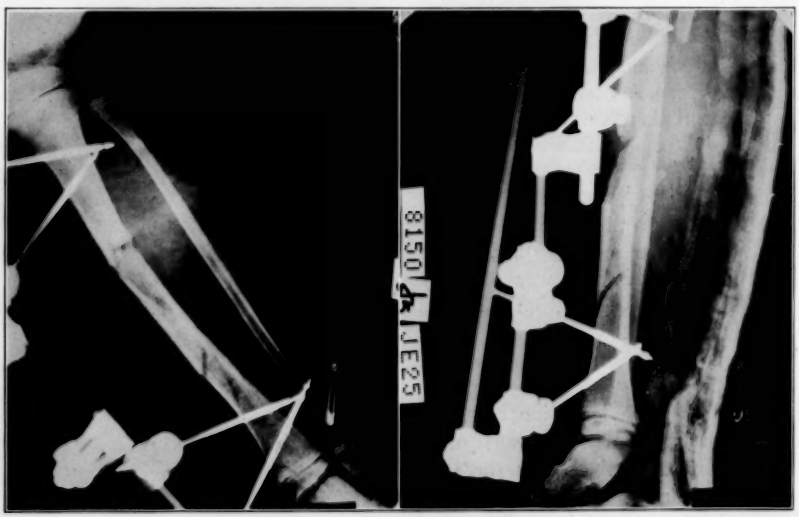

FIG. 6-A
June 25, 1945

Case 105. A four-year-old girl was run over by a truck. The skin of the leg, from the knee to the ankle, rolled off in a large flap with the exception of that on the posterior quarter, where it was attached. It was thought at first that amputation would be necessary and that the child's condition did not warrant even roentgenograms. After thorough cleansing, it was demonstrated that the central fragment was lying loosely in a sleeve of periosteum; actually, the piece was removed from its bed when it was being

(*Continued on page 593*)

FIG. 6-B
January 27, 1946

FIG. 6-C
December 5, 1947

FIG. 6-D
December 5, 1947

realigned, and was held in the air with forceps. The skin flap started just posterior to the fibula and was turned anteriorly and medially. It was not possible to put in through-and-through pins, and even when the check roentgenograms showed the angulation, it was thought unwise to attempt to alter the position. The fractures were united in ten weeks. All of the skin flap had "taken" except a small corner over the inferior part of the fibula, and that was treated by skin-grafting. Revascularization was slow.

Fig. 6-B: Six months later, the girl had the misfortune to slip and to fracture the central fragment. The blood supply was still too uncertain for an attempt to be made to correct the angulation at that time.

Figs. 6-C and 6-D: Comparative anteroposterior and lateral views of both tibiae show sufficient revascularization to allow for a corrective osteotomy. Note the overgrowth of the fractured left tibia, shown in Fig. 6-C.

FIG. 7-A
November 28, 1944

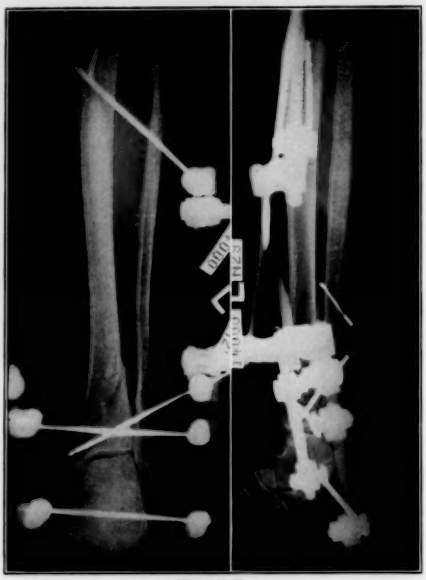

FIG. 7-B
November 29, 1944

Fig. 7-A: Case 64. This patient had a comminuted fracture of the lower quarter of the leg, not involving the joint.

Fig. 7-B: A pin was put through the calcaneus as well, on account of the very short fragment.

Fig. 7-C: Roentgenograms taken over three years later. The patient had no disability.

Fig. 8-A: Case 166. A woman, seventy-five years old, fell on the stairs. The original roentgenograms did not give the impression of the large posterior lip fragment, but an attempt at closed reduction demonstrated the lack of stability.

In the third classification of pin difficulty, there was definite bone involvement. Four patients (Cases 20, 29, 44, and 151) (Fig. 9-A) showed small sequestra about pin sites. After removal of the pins the areas healed immediately, without residual disability; none of these were ring sequestra, but just small flakes about the size of rice. One patient (Case 27A) had some low-grade infection in the head of the tibia with slight persistent drainage, but otherwise with good function.

One patient (Case 186) had sloughing of tissue of the peroneal group of muscles, without apparent infection about the pins and without bone involvement. This patient had a definite lesion of the external popliteal nerve. There have been several transient lesions of the external popliteal nerve; they may have been due to too tight bandaging,

FIG. 7-C
January 7, 1948

FIG. 8-A
September 2, 1946

TABLE I

TIBIAL FRACTURES TREATED BY EXTERNAL SKELETAL FIXATION

Total number of cases	237
Still under treatment (too early for end result)	31
Cases with end-result rating	206
Simple fractures	
Upper third	26
Middle third (approximately middle three-fifths)	90
Lower third without ankle involvement	16
Lower third with ankle involvement	24
Compound fractures	
Middle third (approximately middle three-fifths)	35
Lower third involving ankle	7
Ununited shaft fractures (simple and compound) pinned previously	8
Open reduction	
Without internal fixation	26
With internal fixation	32
Non-union	
Previously pinned simple shaft fractures	2
Previously pinned elsewhere	2
Compound fractures of the shaft	4
Bone-grafting for cases of non-union previously treated elsewhere	11

local swelling, or the close proximity of a pin to the nerve. Recovery occurred in all cases.

One patient (Case 134) had a spiral fracture of the lower end of the tibia in 1945, without involvement of the joint. Pinning was done within two hours of the injury. An extra pin was added because of the very short fragment. Twenty-four hours later, the patient had a sudden severe pain in his leg; the pulsation of the posterior tibial nerve was absent; and the foot was cold. Exploration of the vessel as far as the bifurcation was of no avail, and amputation was necessary later. Examination of the vessel after amputation showed that it had been damaged from the fracture downward, especially above the site of pin insertion.

In addition to Case 212 (Figs. 5-A and 5-B) there was one other patient with ischaemia. This patient had a severely comminuted fracture of the shaft below the head with severe swelling, but without a great amount of pain. In retrospect, it is apparent that the fascia should have been incised.

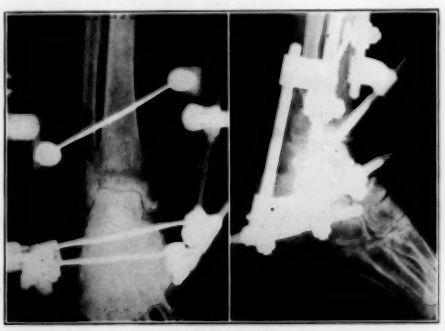

FIG. 8-B
November 13, 1946

FIG. 8-C
January 3, 1948

Fig. 8-B: Ten weeks later, roentgenograms showed the reduction and fixation obtained by the closed method.

Fig. 8-C: Sixteen months after the accident there was a full range of motion, and the patient stated that she had no disability.

FIG. 9-A
April 27, 1946

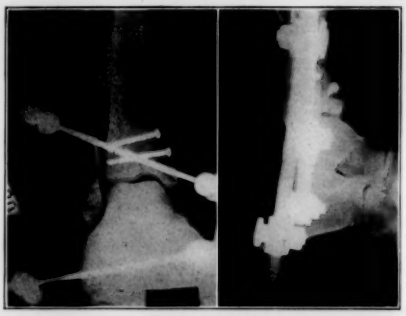

FIG. 9-B
May 2, 1946

FIG. 9-C
October 7, 1947

Fig. 9-A: Case 151. An attempt at closed reduction was made on the ankle, but it was not successful, due to interposition of some small fragments.

Fig. 9-B: After skeletal fixation the roentgenograms showed satisfactory reduction. There was union in thirteen weeks, the patient going back to work in good time.

Fig. 9-C: Eighteen months after the injury, the patient had a small swelling over the middle of the tibia. Roentgenograms show a small sequestrum overlying the exit point of a half-pin. This was removed in the office through a small incision, and the area healed immediately. The end result has been very satisfactory.

Four patients with badly comminuted fractures involving the ankle had severe residual traumatic arthritis, and arthrodesis was required. External skeletal fixation was employed after operation in these cases.

Four cases of non-union occurred among the thirty-five compound fractures of the shaft. Many of the fractures in this group were severely compounded and comminuted, and in some there was loss of substance. The great majority of the compound wounds healed by first intention. In spite of this, however, the operative wounds broke down after bone-grafting in three instances (Cases 25, 125, and 152).

Two compound fractures, primarily treated with pins, were so severe that amputation was necessary eventually. In one (Case 8) there was loss of a large portion of the lower tibia, a large area of skin damage and severe soft-tissue damage, and a nerve lesion. In the second (Case 171), another very severe fracture involving the lower half of the shaft and the ankle, pins were inserted four weeks after the injury, in an attempt to maintain length and allow for some skin coverage. A flare-up of infection necessitated a guillotine amputation. In a third (Case 79), an old ununited compound fracture about the ankle, which was originally infected but had healed, a bad recurrence of infection after bone-grafting made later amputation necessary.

An attempt has been made to give a complete analysis of all the cases with an end-result grading*. One hundred and ten cases were rated $A_4F_4E_4$†. In these cases there was no appreciable shortening, and joint function was through practically a full range; there was only occasional joint pain and no disability. In an analysis of the end results, the good as well as the nearly perfect results were classified in the 4-4-4 rating. These patients have had roentgenographic proof of alignment with films of the knee and ankle joints in almost all cases. The limb lengths were not checked by comparative roentgenograms of the opposite extremity, but only by manual measurement. The 110 cases included seventy closed fractures (simple and complex) and twenty-one compound fractures of the shaft. Five were fractures of the tibial head, involving the joint. Ten cases involved the ankle joint. Four were cases of non-union of the shaft in which bone-grafting and pinning was done.

Very few patients had an appreciable amount of shortening. There was a definite tendency in the early cases toward getting over-extension at the first reduction. This necessitated allowing the fracture to close by loosening the clamps and then tightening them. There was appreciable shortening—that is, over one-quarter of an inch—in only five cases, and these were cases in which there was loss of bone substance. One patient (Figs. 6-A and 6-D) had definite increase in length due to incomplete reduction and associated overgrowth, apparently from fracture hyperaemia.

The general alignment of the fractures has, on the whole, been satisfactory. Two patients had lateral bowing and two had slight posterior bowing, but neither of these conditions was severe enough to require further interference. As mentioned previously, malposition resulted in Case 168 from a broken clamp which was not discovered until one month after the original reduction. In Case 59, the patient had a fracture in the lower quarter with malunion in external rotation due to a poor "technical job" at the time of the original reduction; this was later corrected by a rotation osteotomy, and the end result was excellent.

There were twenty-six fractures of the proximal end of the tibia, twenty-five of which involved the joint. In five the end-result rating was $A_4F_4E_4$. Six patients had tears of the lateral menisci, which were excised. In fifteen of the twenty-one cases, motion of the knee was restricted; three had flexion of less than 90 degrees and the remainder had flexion of 90 degrees or more. Eleven patients had some degree of traumatic arthritis. Three had definite knee-joint relaxation, but none of the knees required arthrodesis.

In thirty-one cases the ankle joint was involved. Seven of these were compound fractures, many of them severely comminuted, with multiple fractures into the joint. Ten of the thirty-one cases had an end-result rating of $A_4F_4E_4$. The three patients with ankle involvement requiring amputation and four requiring ankle arthrodesis have previously been mentioned in the text. Of the remaining fourteen cases, seven had definite ankle arthritis with restriction, one had ankle and knee restriction, and six had some ankle pain.

Of the entire group, twenty-five patients had ankle arthritis and twenty-seven had arthritis of the knee, either alone or combined with restriction. Of this number, ten patients had knee and ankle arthritis, either alone or accompanied by restriction.

The average length of time required for union of the simple shaft fractures was sixteen and one-half weeks; for twenty-eight compound shaft fractures it was sixteen weeks. Union was delayed in eight simple or complex fractures, ranging from twenty-four to thirty-eight weeks. Five compound fractures required from twenty-two to thirty-four weeks for union.

* The review and the grading of the cases from 1942 to 1945 were done by Dr. Giles B. Murphy of the Workmen's Compensation Board of British Columbia.

† The symbols of end-result rating commonly used in the Massachusetts General Hospital, Boston, have been employed. "In each instance the result was evaluated from the separate viewpoint of anatomic restoration (A), functional recovery (F), and effect upon economic ability (E) and was graded on a numerical basis in respect to each of these criteria. The numbers used ranged from 4, the maximum, down to 0." [1]

The average period required in the Hospital after operation was eight days for the simple fractures; for the twenty-eight compound shaft fractures, uncomplicated by other severe injury, it was sixteen days.

When the nineteen patients with non-union (including thirteen originally treated elsewhere) had been treated by bone-grafting and pin fixation, union occurred in twelve to twenty-two weeks in nine cases. In four cases union required twenty-six weeks; in five, twenty-eight to forty-eight weeks. One patient had a severe flare-up of infection and amputation was required.

Associated injuries included three severe head injuries, two of which resulted in the death of the patients; one definite nerve injury; associated fractures,—five of the calcaneus, nine of the pelvis, seven of the femur, four of the forearm, and two of the spine. One patient had bilateral dislocation of the hip with fractures of the pelvis, humerus, and clavicle. There were a number of other associated complications. Of three patients with known fat emboli, one died. Two cases were complicated by pre-existing poliomyelitis.

CONCLUSIONS

This review presents our experience with external skeletal fixation in the treatment of 237 fractures of the tibia, from a total of over 950 cases in which pinning was done for all types of fractures and orthopaedic conditions. In spite of the difficulties encountered, we are still using this method.

1. Massachusetts General Hospital Fracture Service (P. D. Wilson, Editor): Experience in the Management of Fractures and Dislocations (Based on an Analysis of 4390 Cases). Philadelphia, J. B. Lippincott Co., 1938.

DISCUSSION *

Dr. Mather Cleveland, New York, N. Y. (Chairman): Dr. Naden prepared a good deal of this paper while he was undergoing surgical treatment, and he deserves tremendous credit for his willingness to participate in this symposium. We are also obliged to his surgeon for permitting him to be present.

If this method of treating fractures is as good as its proponents say, all fracture surgeons should know more about it. Our Committee on Fractures and Traumatic Surgery is at present, with the full cooperation of our fellow member, Roger Anderson, attempting to study the use of external skeletal fixation in the treatment of fractures. Its use in Army hospitals, as I saw it, was attended with too many complications, such as delayed union, pin-hole infection, and often osteomyelitis. The pins were at times inserted without regard for the anatomical structures between bones and skin, with an occasional disastrous result. The widespread use of this method had to be prohibited; and the apparatus was withdrawn from all except a few hospitals, staffed by competent fracture surgeons, who were allowed to use it where it seemed to be definitely indicated. These external skeletal-fixation splints are not to be entrusted to the inexpert or inexperienced doctor. Even in the expert hands of Dr. Naden, several popliteal-nerve injuries and 5 per cent. of soft-tissue infections or "local irritations" were noted.

Dr. Naden has given some points in technique which should be heeded. He states that he has had no ring sequestra which could be attributed to thermal necrosis of bone. He has been utilizing open reduction and internal fixation, in addition to external skeletal fixation, in an increasing number of patients. Here we see utilization of two methods under discussion today, to emphasize the point that no one method will answer for all fractures. The one obvious advantage of this method is the short period of hospitalization. However, I believe we should know more fully how comfortable these patients are after leaving the hospital within ten days of some of these major injuries.

This is an interesting series of fractured tibiae, and great ingenuity has been shown in their treatment. Many of them were serious problems from the time of onset, and in two cases of compound fracture, amputation was required eventually.

A great deal of additional data, such as function of the adjacent joints, wound healing, and time of bone healing, could be extracted from this wealth of material.

Dr. H. Earle Conwell, Birmingham, Alabama: Dr. Naden's report of 206 fractures of the tibia, treated by external pin fixation, is probably the largest series presented by an individual surgeon. In some of the cases shown by Dr. Naden, the pins are dangerously near the joint; and it would seem to me that such a

(*Continued on page 613*)

* The rest of this discussion was published in *The Journal* in January 1949, with the paper by Edward M. Winant, M.D., and that by Harrison L. McLaughlin, M.D., and his associates.

PATHOLOGICAL CHANGES FOUND IN MATERIAL REMOVED AT OPERATION IN LEGG-CALVÉ-PERTHES DISEASE *

BY SAMUEL R. HAYTHORN, M.D., F.A.C.P., F.P.A.C., PITTSBURGH, PENNSYLVANIA

From the William H. Singer Memorial Research Laboratory of the Allegheny General Hospital, Pittsburgh

In 1941, Steele reported a series of cases of osteochondritis deformans juvenilis (Legg-Calvé-Perthes disease) in which he had performed operation in the hope of hastening healing and shortening the period of disability. He reasoned that, if the debris of the necrotic tissue were removed, the head were filled with healthy bone grafts, and the extremity were put at rest, healing would take place rapidly. His operation consisted in opening the joint and cutting a door, approximately one-half inch long and one-quarter inch wide, in the superior anterior surface of the head and neck, so that the opening crossed the epiphyseal line. He chose the superior anterior surface so that, if any interference occurred, it would result in coxa valga instead of coxa vara. He curetted out the degenerated tissue through this door, packed the cavity with bone curls from the femoral neck, and closed the wound. Following the operation, the patient was kept at rest in bed with a lightweight extension for at least three weeks, and then was allowed up on crutches. In most of the cases, the period of regeneration was reduced to about six months and the results were satisfactory.

The material upon which this pathological report is based was obtained by curettement of the head of the femur in thirty-six patients, operated upon in the Orthopaedic Department of the Allegheny General Hospital **. Thirty-three cases were considered clinically, pathologically, and roentgenographically to be Legg-Calvé-Perthes disease; one proved to be a very early osteogenic sarcoma; one was an early osteomyelitis following injury; and one was complicated by bilateral dislocation of the hip. In addition, material curetted from the head of the femur in patients over twenty years of age was examined, and was found to differ from that seen in the average case of Perthes' disease by the absence of endochondral osteogenesis.

The point has been raised that the fragmentary nature of tissue obtained by curettement necessarily limits the interpretation of the relationship of the changes which existed within the femoral head before surgical removal. In a measure that is true, yet the pieces were large enough to determine the character of the lesions and the relative degree of pathological change. The opportunity to review and compare the lesions in thirty-three cases of the disease was unusual and partially offset other disadvantages.

As would be expected, the curetted material was not alike in all cases, even though it was made up of similar elements. Wider ranges and degrees of changes were seen than those described in reports of single cases. Many of the pieces could be identified by their histological structure, and could be used to postulate their probable positions in the original lesions. The reports of cases like those of Gall and Bennett and of Zemansky, where whole femoral heads were examined, were especially helpful in the theoretical reconstruction of our cases. Furthermore, with curettage there was no opportunity to examine the ligamentum teres for the vascular changes which have been described as having a causal relation to the necrobiosis.

ROENTGENOGRAPHIC FINDINGS

The roentgenographic findings are typical, although there is a discrepancy between the roentgenograms and the appearance of the femoral head when exposed at operation.

* Presented at the Annual Meeting of the Association of American Pathologists and Bacteriologists, Philadelphia, March 12, 1948.

** Twenty-six cases were on the Service of Paul B. Steele, M.D., and ten on the Service of J. A. Heberling, M.D.

The usual roentgenographic findings, as described by Hodges, Phemister, and Brunschwig, consist of flattening of the femoral head with fragmentation and sometimes cavitation of the ossification center. The process may involve the epiphyseal line, causing the neck to become broader than normal. Sometimes an oval area of reduced density develops in the lateral portion of the neck. In untreated cases of long standing, the head becomes too large for the acetabulum, extends beyond it, and has the appearance of having been crushed by the acetabular rim. The descriptions made at operation would indicate that the appearance of crushing was more apparent than real. The head was not flattened, as it appeared in the roentgenogram, but remained spheroidal; and the cartilage appeared normal except for thickening. The gross appearance of the acetabulum was normal.

Gill [7], who made extensive roentgenographic studies, divided the disease into a degenerative phase, lasting approximately one and one-half years, an abrupt turn in the cycle, and the final regenerative phase, which is completed in from two to three years. He found that the course could be shortened by rest and mechanical means, which take the pressure of weight-bearing off the hip. In several of his cases the condition was discovered by roentgenograms before the onset of symptoms, and the earliest lesions seen were areas of necrosis in the metaphysis of the neck of the femur, manifested by irregular "holes" in the bone of the neck. These usually appeared at the lateral margin of the epiphyseal cartilage, although the central and medial margins were occasionally involved. Subsequent degenerative changes occurred in the head of the femur; the first region affected was that which directly overlay the degenerated area in the metaphysis. Later, decalcification or so-called fragmentation, with isolated areas of increased density, appeared. These finer changes were followed by those alterations in the size and shape of the head which are

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. In N. T., a white boy, aged four years, symptoms had been present for two months before operation. Diagnosis of Legg-Perthes disease was made clinically and roentgenographically. The head is of the mushroom type. A reaction resembling that of a benign giant-cell tumor came from the material curetted from this head. Nothing resembling a bone cyst is seen in this roentgenogram.

Fig. 1-B: This was the first patient operated upon by Steele, and bone grafts were not inserted at the first operation.

Roentgenogram taken seven months after first operation. As healing was not complete, the head was again curetted and bone grafts were driven in. Healing followed. Bone grafts from neck of femur were used in all other cases.

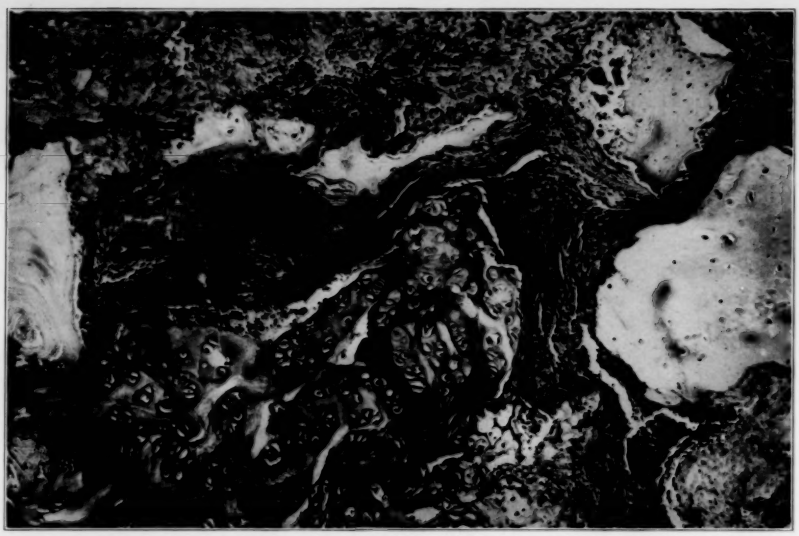

FIG. 1-C

Pathologically, this was grouped with ten other cases showing bone-cyst formation, and had the most pronounced symptoms in the group. Note the very dense fibrous replacement in the marrow spaces, loss of polarity of the chondrocytes, and presence of osteoid tissue (× 175).

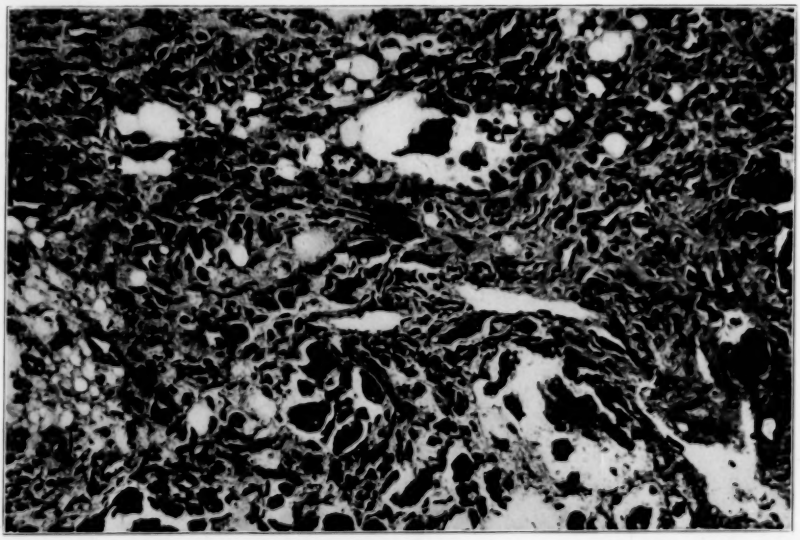

FIG. 1-D

Several cyst walls contained areas resembling benign giant-cell tumors. They were small and diffusely placed, and were backed up by bony spicules. Note the fatty stroma, the generally parallel arrangement of the fibroblasts, and the multinucleated giant cell (× 175).

generally accepted as typical of the disease. Gill's observations are interesting in light of the histopathological finding of small bone cysts, to be described later.

Lipscomb and Chatterton, in 1942, by means of roentgenographic studies, described changes in the acetabulum which accompanied those of the head of the femur. Gall and

Bennett verified the acetabular involvement in their report of a case with autopsy. They found increased lacunar resorption of bone and irregularities in endochondral ossification. Burrows stated that 10 per cent. of the cases are bilateral; Hagen reported bilateral occurrences in each of two brothers, and suggested a familial tendency.

In our series, the roentgenograms were typical of Legg-Perthes disease. They showed variations in the amount of deformity and in the density of the femoral head, sometimes with considerable distortion of the head. The heads often appeared to be flattened, sometimes with a mushroom or cap-shaped appearance. When the joint was opened, the distortion and flattening were much less evident than the operator had been led to expect.

MACROSCOPIC CHANGES

Zemansky, who reported a case of Legg-Perthes disease in which the femoral head was resected, described the macroscopic appearance as follows: The cartilage over the head was thrown into folds with deep crypts between. The cartilage was clear, white, and glistening. In the depths of a crypt was a dark red area, suggesting hemorrhage. The outermost portion of the cartilage was lifted from the underlying bone and hung in shreds. Gall and Bennett reported a case with autopsy, and found that the head was flattened on the superior surface and covered with smooth, normal-appearing cartilage. The acetabulum appeared normal; the synovial membranes showed slight villous hyperplasia; and the ligamentum teres was slightly flattened. In Lippmann's case, flattening of the crest and grooves were present grossly, and the ligamentum teres protruded sharply from the fovea capitis. It was swollen and oedematous.

The gross descriptions in our cases were made at operation by the surgical assistants. The majority of the heads were described as spheroidal, smooth, and glistening, and the cartilage was said to be unusually thin. Some showed slight flattening with cartilage of uneven thickness; some were said to be slightly "eroded". Others were fragmented, and

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 3. R. B., a white girl, aged five years, had had symptoms for about six months before operation. The clinical, roentgenographic, and pathological diagnosis was Legg-Perthes disease. Pathologically, the case presented all of the changes except bone-cyst formation.

Fig. 2-B: Four months after operation, the condition was healed. Shortening and thickening of the neck were present.

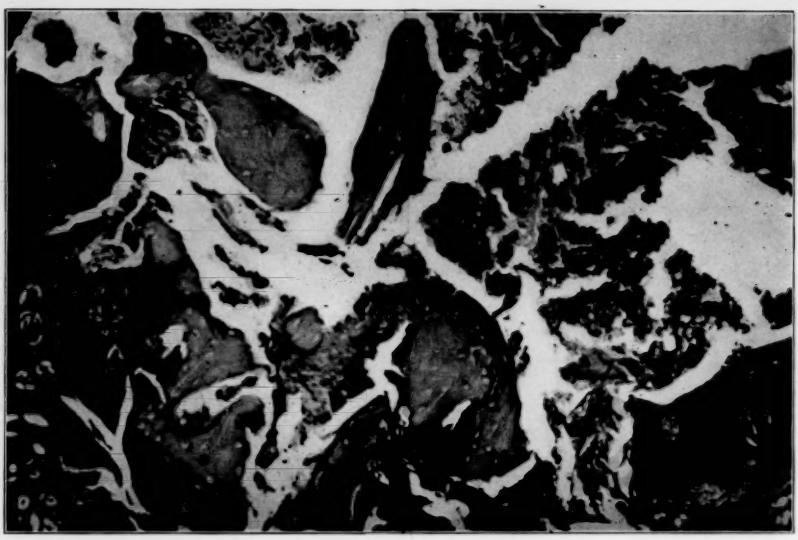

FIG. 3

Case 8. In L. H., a white girl, aged seven years, symptoms began four weeks before operation. Clinical and roentgenographic diagnosis of Legg-Perthes disease was made. Pathologically, the case was grouped with the predominantly degenerative lesions. The upper right portion shows marrow spaces, filled with necrotic material. Two bony spicules are necrotic. At the left and below are broken lines of osteogenesis. In the left lower corner the chondrocytes have lost their polarity (× 135).

one or two were loosened. In two or three instances, intracartilaginous cysts were mentioned. The contents of the heads were described as cystic and as containing soft spots, necrotic material, and softened bony spicules. Four cases showed hyaline cartilage, extending down the neck as far as the trochanter. In one instance a band of inflamed connective tissue was found, attached to the neck. In several cases small cystic areas were present in the neck, and evidence of bony absorption of the neck was mentioned twice. No inflammatory processes were described in the soft tissues, and nothing was said concerning the ligamentum teres.

In the laboratory, the tissue obtained by curettement was described as soft, necrotic, and as containing bony spicules and bits of cartilage. The color of the contents was generally given as brownish-red. All the curetted material had to be decalcified before being sectioned.

HISTOPATHOLOGICAL CHANGES

In the thirty-three cases that were clinically, pathologically, and roentgenographically identified as Legg-Perthes disease, the microscopic changes followed a similar pattern. Usually the biggest piece was cartilage, and could be identified as a part of the surgical door, removed at operation to gain entrance to the femoral head and neck. In some of the cases the door was sent as a separate specimen, with a different number. Smaller bits of cartilage, with degenerated areas on two sides, were accepted as portions of the epiphyseal cartilage. Hemorrhage was a constant feature, but was discounted, since the material had been scraped out of the head or neck with a curette.

It would involve too much repetition to give either the clinical histories or the pathological changes for each case. The lesions will, therefore, be discussed, and the cases will be grouped according to the predominating changes found.

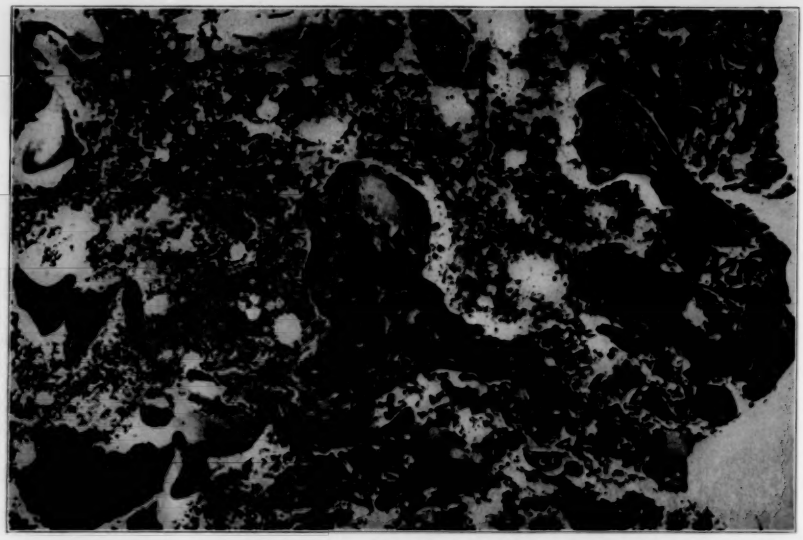

FIG. 4

Case 13. F. H., a white boy, aged seven years, had had symptoms for eleven months before operation. Clinical and roentgenographic diagnosis was Legg-Perthes disease. Pathologically, it was grouped with the degenerative and crushing lesions. The marrow spaces are filled with debris and displaced bony spicules. In the lower central areas and in the upper right portion, irregular ossification is taking place (× 135).

1. *Degenerative Changes*

In every case, more or less degeneration, necrobiosis, or necrosis was present without any local evidence of the cause. The least destructive lesions involved the contents of the marrow spaces, and consisted of necrosis of the cells and stroma. There was constantly a diffusion of chromatin throughout the area, and the fatty stroma disappeared, together with normal marrow cells. In some such areas there was no evidence of repair, while in others the spaces were filled with a loose, watery-appearing fibrous tissue, infiltrated with a few lymphocytes and mononuclear cells. Some of the mononuclears were phagocytes for blood pigment and other debris. In some of the cases atrophic marrow with a few persistent marrow cells occupied spaces adjacent to the necrotic areas. Segmented leukocytes were uncommon, and in only two of the cases were they present in numbers sufficient to raise the question of concurrent infection. The absence of infection was supported by many negative cultures. In more advanced lesions, necrosis was extensive and complete, involving not only marrow, but cartilage and bony spicules from broken trabeculae. With necrosis as a basis, other changes to be described were superimposed.

2. *Crushing in Necrotic Areas*

In six cases, there was a pronounced appearance of crushing or jamming together of the degenerated elements, with too many different processes involved for the spaces they occupied. There was no gross evidence of crushing of the head in these cases, which made the finding hard to explain. As weight-bearing is generally accepted as a contributing cause and relief from it as sound treatment, it is probable that the femoral head is more resilient *in situ* than it appears, and permits the transmission of pressure to its contents. Again, in some cases the process may be more active than in others and may actually show more changes per cubic millimeter. Finally, the crushing may not have existed in the head, but may have been caused by the pressure of the curette on unusually soft material.

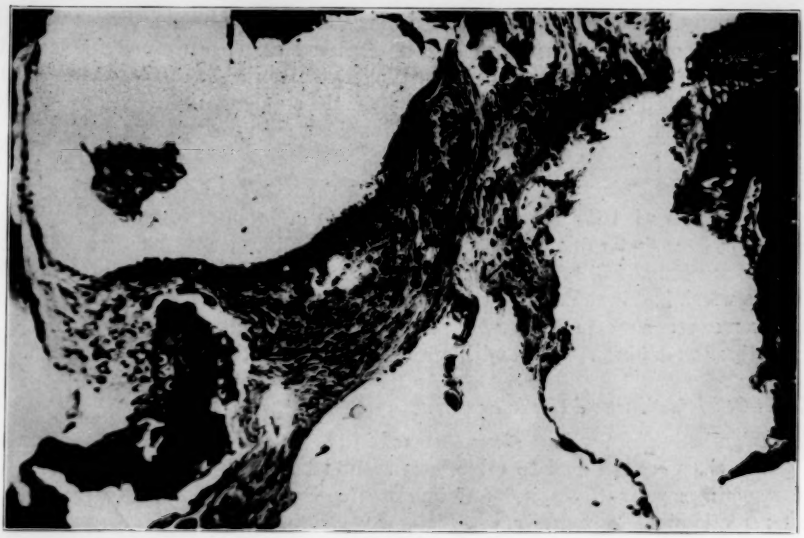

FIG. 5-A

Case 10. E. H., a white boy of eight years, had had symptoms for two years. The clinical and roentgenographic diagnosis was Legg-Perthes disease. Pathologically, this was grouped with the fibrocystic cases. Other fields were typical of the disease. A portion of three cysts is shown (× 135). The walls are fibrous and contain small giant cells.

FIG. 5-B

In the upper left corner, the polarity of the chondrocytes is disturbed and irregular ossification is present. The dense type of fibrous replacement of marrow, regularly found in cases of Legg-Perthes disease with cysts, is seen in the upper right corner. A cyst with fibrous and bony walls is found in the center, and bony-walled cysts, lined by a thin, fibrous layer, occupy the zone at the lower left (× 135).

The normal architecture was lost in these cases, and necrotic tissue was compressed between pieces of bone and osteoid tissue in a conglomerate mass. Bits of cartilage, bone, and granulation tissue were compressed into about half the space that such structures

would normally have occupied in unaltered bone. The intratrabecular spaces were filled with homogeneous debris. Irregular bits of displaced cartilage showed fragmentation with loss of nuclei, while others were undergoing ossification. The cartilage in these areas apparently included bits from the operative door, the epiphyseal cartilage, and pieces of stray cartilage distributed indiscriminately throughout the head.

3. *Reparative Processes*

Side by side with the degenerated areas, islets of healing were commonly found. These varied from simple fibrous replacements of marrow, infiltrated sparsely with lymphocytes and occasional leukocytes, to dense bands of compact fibrous tissue. All through the tissue which had been curetted, there were trabeculae of bone having unossified centers. In some cases almost normal osteogenesis was present in one piece, while in neighboring bits there were fibrous cysts and heteromorphic osteoid tissue under formation.

4. *Giant-Cell Reactions and Cystic Reactions*

Foreign-body giant-cell reactions occurred in twelve cases. This does not mean that the giant cells were confined to osteoclasts around bony spicules, although they, too, were sometimes present. Typical multinuclear foreign-body giant cells were collected about necrotic areas in several cases. Lippmann mentioned giant cells as a part of the inflammatory reaction in his case. In some of the cases thick, fibrous bands of connective tissue were present, which formed cysts, resembling a reaction of osteitis fibrosa cystica. Giant cells might or might not be present in the cyst walls. In one case, which was otherwise typical of Legg-Perthes disease, there was a giant-cell cyst resembling a benign giant-cell tumor; and in another, a small osteoid osteoma, no larger than the head of a pin.

5. *Changes in Cartilage*

As already mentioned, the loss of polarity of the cartilage cells was the outstanding cartilaginous change, and was present to a greater or lesser extent in all cases. The chondrocytes were arranged in angular patterns, suggestive of constellations on the blue cartilaginous backgrounds. Many pieces of cartilage were penetrated by arterioles with a border of mesothelial tissue about them. Some of the spaces were filled with blood; in others the vessel was no longer present, but a small cystic space containing red cells persisted. Such changes occurred in the cartilage from the operative door, epiphyseal cartilage, and stray bits of cartilage from incompletely ossified trabeculae, indiscriminately distributed throughout the femoral head.

6. *Vascular Changes*

As a rule, there were no vessels in the degenerated areas. Capillaries and thicker-walled arterioles were present in the marrow spaces and were especially prominent in those filled with fibrous tissue. There were no consistent vascular changes and no thrombi. The presence of intermingled living and dead tissue seemed to argue against infarction as the cause of the necrosis.

7. *Resemblance to Scurvy and Rickets*

Burrows mentioned two cases of bilateral Legg-Perthes disease, complicated by rickets. Some of the lesions in our cases were suggestive of the changes seen in scurvy,—that is, there was no normal set pattern of ossification. There was an excess of calcification in places, displaced osteoid tissue, and fibrous replacement of the marrow. Some changes also resembled rickets in that there was no line of demarcation between bone and cartilage; there were displaced osteogenic patches; and numerous osteoblasts and osteoclasts were seen in the ossifying areas.

Summary of Histological Changes

The presence of aseptic necrosis affecting marrow, cartilage, and bone, the fibroblastic changes, and the uneven lines of osteogenesis were consistent with the findings of

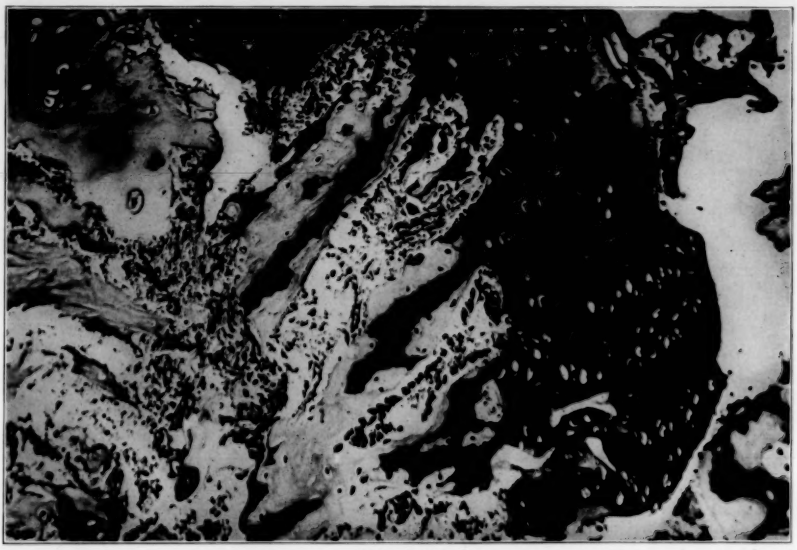

FIG. 6-A

Case 31. E. T., a white boy of seven years, had had symptoms for six months before operation. Clinical and roentgenographic diagnosis was Legg-Perthes disease. Pathologically, this case showed all of the changes characteristic of the disease and, in addition, a portion in which ossification was more or less orderly. The chondrocytes at the right side are arranged in parallel columns and the osteoblasts appear normal, while the marrow spaces in the lower left corner are filled with necrotic tissue (× 90).

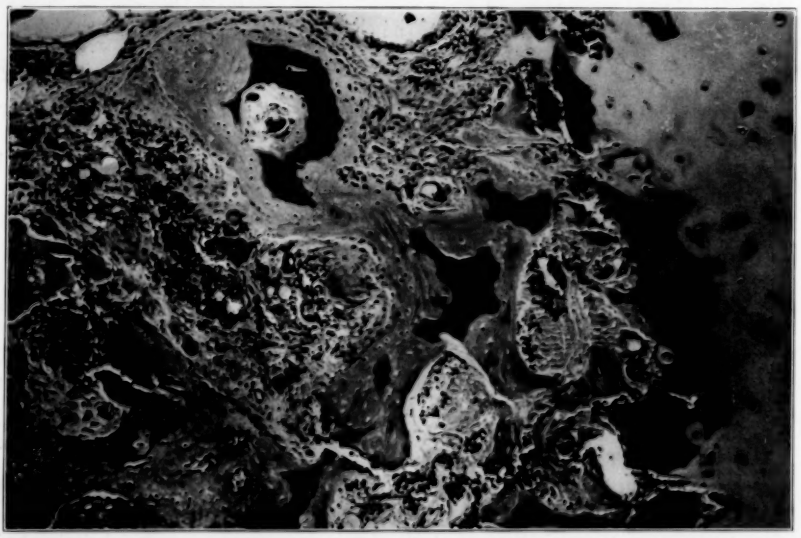

FIG. 6-B

An area (× 90) showing almost all of the pathological changes of Legg-Perthes disease. Note the resemblance to scurvy.

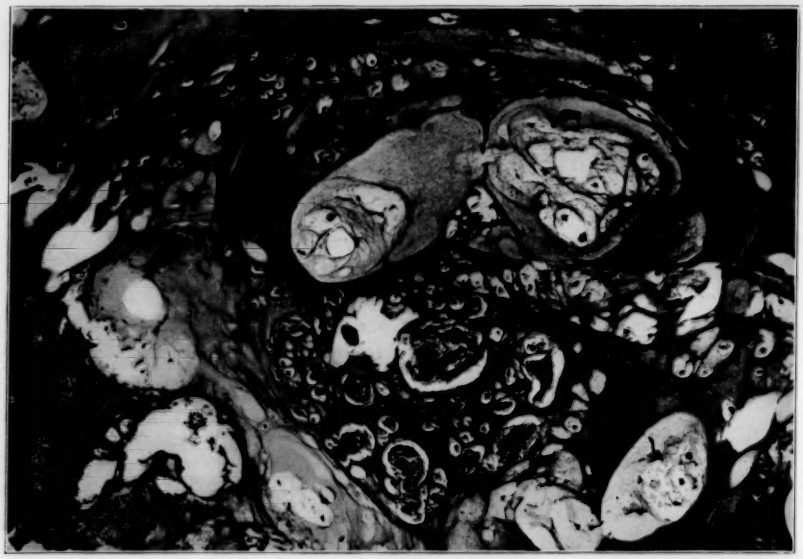

FIG. 7

Case 16. G. H., a white boy, aged five years, had had symptoms for one year. Note the loss of polarity and distortion of chondrocytes in epiphyseal cartilage. Note cystic changes in the chondrocytes (× 120). The patient improved after operation, when given chorionic gonadotropin.

Zemansky, Gall and Bennett, Lippmann, and others. The general plan of the lesion was similar for all cases, but the variation in degree of the respective changes was considerable. Giant-cell reactions have been mentioned in other papers, although the presence of fibrous cysts, benign reactions like those of giant-cell tumor, loss of polarity of the chondrocytes, and hemorrhagic cysts in the cartilage have not been emphasized. Attention has also been drawn to the resemblance of the changes both to scurvy and to rickets.

Relation of Age of Patient and Duration of Symptoms to Type of Histological Lesion

All of the cases were restudied to see if there was a consistent relationship between the lesion, the duration of symptoms prior to operation, and the age of the patient.

Seven cases that were predominantly of the degenerative type occurred in children from four to ten years of age. The symptoms had been present from three weeks to eleven months. Crushing or apparent collapse and moderate repair occurred in patients from seven to eleven years, with symptoms present from one week to twenty months. Cases in which there was a predominance of reparative changes included patients whose ages varied from five to twelve years and whose symptoms had been present from five to eighteen months. The largest group, that with fibrous-cyst formation, included twelve cases,—seven in which the cyst walls had few or no giant cells, and five in which giant-cell cysts were sufficiently prominent to suggest benign giant-cell tumors. As mentioned before, in one case the reparative process stimulated a small osteoid osteoma. It was expected that this group would be made up of older children with symptoms of several months' duration, but it was not. For example, the most pronounced case of cystic change was in a boy aged four, whose symptoms had been present for only two months. All of the children in this group were between four and eight years of age, and their symptoms had been present from two to eighteen months. Save that all of the cases were prepuberal, it is obvious from these data that no relationship was found between the age of the patient, the onset of symptoms, and the type of lesion.

Histopathological Findings Bearing upon Hypotheses of Pathogenesis

The actual cause or causes of Legg-Perthes disease are not known, although many hypotheses have been advanced. The more common ones will be discussed in the light of the histopathological findings which tend to support some of them, throw doubt on some, and exclude others. The therapeutic agents mentioned in the discussion are not cited for the purpose of treatment, but because they seem to give indirect evidence that endocrine disturbances are allied with pathogenesis.

Trauma is the most commonly cited pathogenic factor. Legg suggested trauma as the probable cause in thirty-seven clinical cases. Goldenberg reported five cases from the literature and one of his own in which Perthes' disease followed injury; one was a traumatic dislocation of the right hip followed by Perthes' disease. Many other authors have considered trauma the most important etiological factor. In seven of the author's cases there was a history of accident, but all of them were more or less trivial,—one child twisted a leg while swimming; one was kicked by another boy while playing; the most severe accident was a fall from a four-foot wall. In the other cases, the disease developed insidiously, so it seemed probable that the accidents were precipitating factors rather than actual causes. Microscopically, the only evidences of injury were possibly those of slow crushing and repair. In no case did the reparative changes suggest callus formation, either recent or late.

Among other conditions that have been suggested as causes of Legg-Perthes disease are acute infections, particularly those produced by *Streptococcus viridans* [15], tuberculosis, syphilis, and congenital anomalies. They could all be excluded in our series, because the lesions which characterize them were absent from the histological sections.

Several references in the literature indicate an association with vitamin and hormonal deficiencies and with other metabolic disturbances. Hyperparathyroidism has been suggested. Our cases with bone cyst-like changes resembled osteitis fibrosa cystica in a measure. Where blood-chemistry studies were made, both by Gill [8] and by the author, no consistent disturbance was found in the calcium-phosphorus-protein-phosphatase ratios. Moreover, the cysts were confined to the femoral heads and were usually solitary. In Gall and Bennett's case, there were disturbances in most of the blood-chemistry constituents. The patient was a boy who had long been known to have renal insufficiency, suggesting that factors other than Perthes' disease were responsible for the chemical disturbances.

Hypothyroidism has received more support than hyperthyroidism. Albright likened the changes in the hip joints to those occurring in cretins, and reported a case that improved under thyroid administration. Cavanaugh, Shelton, and Sutherland, and Schaefer and his associates found evidence of an association between Legg-Perthes disease and hypothyroidism. Cavanaugh, Shelton, and Sutherland reported five cases in which the patients improved after thyroid administration. Gill [8], after careful study of twenty cases, including blood-chemistry tests, basal-metabolic examinations, and roentgenographic plates for bone age, concluded that there was no evidence that the disease was due to hypothyroidism.

The bone age lagged behind the chronological age in all five cases of Cavanaugh, Shelton, and Sutherland. One showed the stigmata of sexual underdevelopment. Gill found the bone age less than the chronological age in some cases, and synchronous with it in others. Bone-age studies in the present series were done on those cases referred to our Research Department in Endocrinology and Metabolism *. Generally the bone age was behind the chronological age, but in one case the bone age was greater. Grauer considered this case to be a hypothalamic type, and the patient was treated with chorionic gonadotropin and with growth complex. Recovery was rapid without operation, and there was no opportunity to examine the contents of the femoral head.

* R. C. Grauer, M.D., Director of Research.

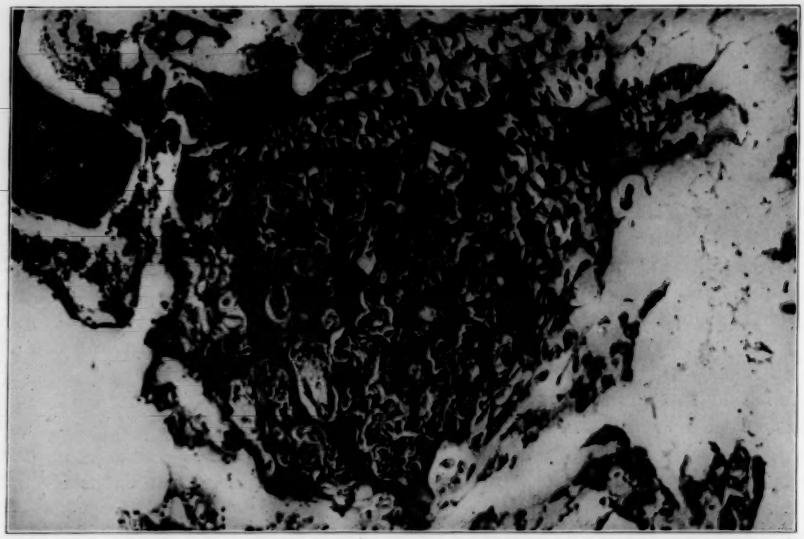

FIG. 8

Case 24. J. S., a white boy, aged eleven years, had had symptoms for seven months before operation. The case was clinically, roentgenographically, and pathologically Legg-Perthes disease. The photomicrograph (× 135) shows a small area resembling an osteoid osteoma. The structure was smaller than the head of a pin.

The cartilaginous changes in Case 16 were unusual.

In G. H., a white boy, aged five, who was obese, had a small penis, retractile testes, and other signs of sexual underdevelopment, healing was not so rapid as usual after the Steele operation. The roentgenograms of the hip were typical. The patient was referred to the Department of Endocrinology and was treated with chorionic gonadotropin; he made a gradual but complete recovery. On restudy of the sections, it was found that the changes were typical of Legg-Perthes disease, except that the normal osteogenic pattern in the epiphyseal cartilage was absent. It was replaced by a radial pattern with a central hub, made up of giant-sized cartilage cells lying in cystic spaces (Fig. 7). Radiating from it were columns of cells which varied in size and staining reactions. There was no bone formation in the nucleus, although there were bony trabeculae on each side of it.

The case is cited for its probable relationship to sexual underdevelopment. Grauer thinks that Legg-Perthes disease is not necessarily related to sexual deficiencies, but that several metabolic disturbances may be partially responsible and that each case should be studied individually.

Brailsford, Ferguson and Howorth, Lippmann, and others believe that the necrosis is due to changes in the blood supply. There were few vessels of appreciable size in the tissue curetted; there was nothing in our material either to confirm or deny the importance of such changes; and the ligamentum teres could not be examined.

We examined tissue curetted from the femoral head in two cases diagnosed as osteochondritis coxae in patients between twenty and thirty years of age. Both showed fibrous replacement of marrow and one had a small exostosis. There was no irregular line of ossification or endochondral osteogenesis, and, in the absence of fracture, none should be expected, because union of the epiphysis and metaphysis is usually completed at the age of eighteen.

CONCLUSIONS

1. The changes in the head and neck of the femur in children with Perthes' disease were constant within fairly narrow limits, and included aseptic necrosis or necrobiosis, evidence suggestive of crushing, concurrent degeneration and repair, partial ossification of displaced cartilaginous tissue, loss of polarity of chondrocytes, small cartilaginous

cysts, and areas of fibrous-cyst formation with giant cells in the walls, similar to those found in osteitis fibrosa cystica.

2. The pathological changes are those of disturbed metabolism rather than of trauma or infection, and suggest that each case should be studied for bone age and disturbances due to hormone and vitamin deficiencies. As no single deficiency seems to be present in all cases, each case should be studied individually.

3. Removal of the contents of the head should in itself be beneficial, since it eliminates debris that may lead to the formation of cysts and giant-cell reactions.

4. The interpretation of Legg-Calvé-Perthes disease, based on a study of the material presented, is (a) that the disease is primarily a prepuberal degenerative condition with aseptic necrosis of the epiphysis and upper portion of the metaphysis of the femur, depending in part upon some deficiency; (b) that the head becomes weakened to the point where weight-bearing injuries lead to slight flattening; and (c) that the remainder of the changes result from frustrated attempts at healing, which are obstructed by the presence of degenerated and displaced bone constituents and further complicated by the continued injuries of weight-bearing.

NOTE: The author's sincere thanks are acknowledged to Paul B. Steele, M.D., and J. A. Heberling, M.D., of Allegheny General Hospital, for the privilege of reporting the pathological findings in their cases and for assistance in studying their records.

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LOW INSERTION OF THE HIP NAIL*

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One of the common causes for failure in the internal fixation of fractures of the neck of the femur and of intertrochanteric fractures is that the metal cuts its way out of the head or neck. This is sometimes due to a marginal position of the nail or screw in the head[1, 2, 3, 4], and, particularly in intertrochanteric fractures, to a low insertion of the nail.

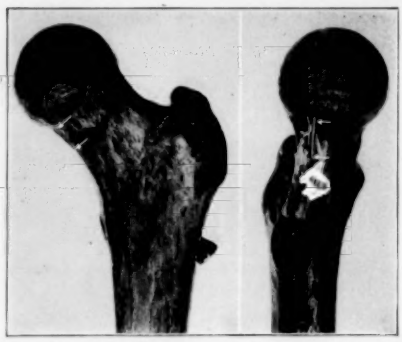

FIG. 1-A

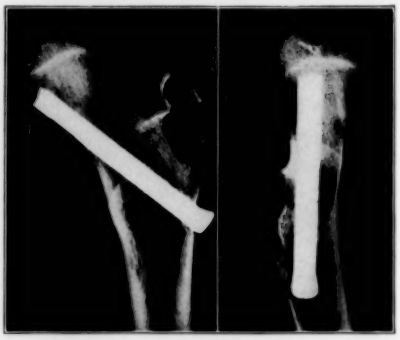

FIG. 1-B

Photographs and roentgenograms of the femur, illustrating too low insertion of the nail.

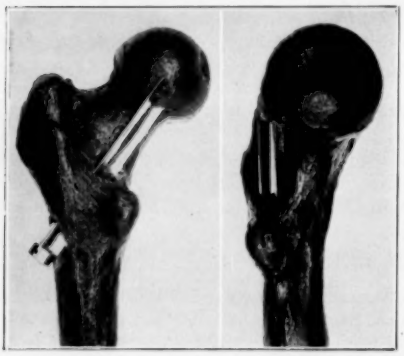

FIG. 2-A

FIG. 2-B

Posterior and lateral views of low nail, placed posteriorly.

There is a lengthwise ridge of bone in the neck of the femur, in the roentgenographic shadow of which a badly placed nail or other device for internal fixation may give the deceptive appearance of being within the confines of the bone. In cross section, the neck of the femur has the shape of a teardrop. A nail inserted in the bulge of the teardrop is actually centrally placed and so appears in the anteroposterior roentgenogram. On the other hand, a nail which has been inserted too low in the neck may lie in part outside the

* Demonstrated as Scientific Exhibit, at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 22–27, 1949.

** Formerly Fellow in Orthopaedic Surgery, Northwestern University Medical Specialty Training Program.

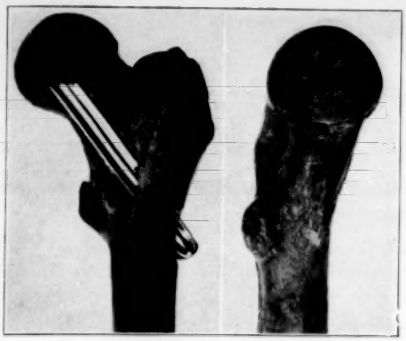

FIG. 3-A

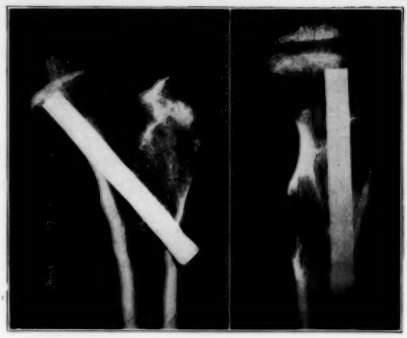

FIG. 3-B

Fig. 3-A: Low nail, placed anteriorly.
Fig. 3-B: Although nail lies outside the neck, in the roentgenograms it has the appearance of lying within the neck.

cortex, and yet give the roentgenographic appearance of being within the neck (Figs. 1-A through 3-B).

Both roentgenographic projections must show the nails or screws to be centrally placed. Maximum engagement in the bone of the head is obtained by the avoidance of marginal placement.

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DISCUSSION

FRACTURES OF THE TIBIA

(*Continued from page 598*)

situation risks joint injury, if not delayed function of that joint. In certain cases I would have used skeletal traction and later a cast, and in other cases I would have done a simple closed reduction and applied a cast to the extremity with the expectation of good results. In one case that Dr. Naden showed, in which the patient had a rather marked oblique fracture of the lower end of the tibia with displacement, as well as a fracture through the upper end of the fibula, I would have done a simple internal fixation by using screws. Such open operative technique is generally simpler than prolonged external pin fixation and produces, in my opinion, less potential infection than external pin fixation.

The following remarks do not apply exclusively to the technique used in Dr. Naden's cases. However, in order to present a fault of internal pin fixation (one example being the intramedullary pin advocated by Küntscher and others), I wish to say that the intramedullary peg was discarded years ago. I refer particularly to the beef-bone peg used by Hendon and the cow-horn peg used by Fowler and others. The objection to such intramedullary peg fixation was that it produced too much trauma to the vital bone-healing area at the fracture site, causing non-union in a large number of cases. Too often such treatment requires a more radical surgical approach than does simple internal fixation. A complicated fracture results, and more trauma is produced than by doing a simple open internal fixation. Let's not be misled by a faddist treatment, but deal with each case as an individual problem, and apply the treatment to the fracture and not the fracture to the treatment.

(*Continued on page 618*)

THE DISC SYNDROME

Results of the Conservative Care of Patients with Positive Myelograms

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Since Mixter and Barr first presented the concept of back pain and sciatica resulting from a displaced nucleus pulposus, this syndrome has been recognized with increasing frequency. As with most scientific advances, the clarification of the pathological changes has raised a host of new problems, which are still partly unanswered. The role of the herniated disc in the broad picture of backache and radicular pain is controversial. Some clinicians believe that the disc accounts for a small fraction of such cases, while others believe that all back pain with radiation is encompassed within its limits. Widely divergent views exist regarding operative indications, the extent of the operation to be done, and the question of whether or not spine fusion should follow disc removal.

A start has been made on the clarification of some of these problems. The results of disc surgery have been adequately reported in articles by Grant and his associates, Shinners and Hamby, and Lenhard. Less has been reported, however, about what happens to those patients with clinical and myelographic evidence of a definite disc lesion, who have been treated conservatively. Conservative treatment of proved ruptured intervertebral discs is not widely accepted. A report of such a nature has been made by Kirstein. In a review of the literature, no others were found. It is the purpose of this paper to examine the results of this form of therapy.

At the Hospital of the University of Pennsylvania, almost all of the cases of low-back pain and radicular pain are treated by a period of conservative therapy, consisting of bed rest on a firm support, traction, adequate sedation, daily physical therapy, and, when the patient is ambulatory, some form of back support. If the patient fails to respond to these measures within a few weeks, and if there is a history of repeated attacks of severe pain, a myelogram is indicated. If he is having an acute, intractable attack, and if there is definite myelographic evidence of a protruding mass, surgery is usually resorted to.

The selection of patients for results on a non-operative basis poses a problem not encountered in the reporting of an operative series. Employing only clinical means, can one beyond question select a patient having a ruptured or protruding nucleus pulposus? The authors believe this is not possible at present. At this time myelographic studies, with pantopaque as the contrasting medium, offer the best confirmatory evidence of the presence or absence of protrusion of the dural contents or its roots. Factors as yet incompletely investigated prevent a final, certain diagnosis from clinical findings alone. Some of these are the role of the concealed or hidden disc, injury to the annulus, root adhesions, inflammatory changes of the nerve from adjacent arthritis, pressure changes in the foramen, and referred pain from ligamentous injury or postural strain,—all as yet to be completely unraveled.

The group included in this study is small, but has been carefully reviewed. Of twenty-eight patients studied, twenty-three were examined personally and the other five gave complete answers to a questionnaire. In each patient a clinical diagnosis of protruded nucleus pulposus was advanced. Such a diagnosis was usually based on a history of backache and radicular pain, associated with findings of impaired spinal mobility, spasm of the erector muscles, positive straight-leg-raising test, and sciatic scoliosis. In addition, reflex

sensory changes and atrophy of the lower limb were commonplace. Routine roentgenograms of the lumbar spine and pelvis were either negative or showed some intervertebral narrowing. The patients were seen in consultation in the departments of Orthopaedic Surgery, Neurosurgery, and Neurology. Each patient was given an oil myelogram by members of the Radiology Department; a definite diagnosis of a protruding mass in the lumbar canal was noted under the fluoroscope and was confirmed by anteroposterior, oblique, and lateral views of the oil column. Patients with only air myelograms were excluded from this study because of the unreliability of this diagnostic medium. In a previous report[4], air and oil myelography was correlated with operative findings. This showed a high degree of accuracy for oil, but negative air studies could not be regarded as conclusive.

The twenty-eight patients in this study were followed from one to eight years after myelography, with an average follow-up of 2.7 years. Nineteen males and nine females comprised the group. The average age was thirty-nine; the oldest patient was sixty-seven and the youngest, seventeen years. All patients were treated with braces, restricted activity, and physical therapy following their hospitalization. Twenty lesions were in the fourth to fifth lumbar interspace, six in the fifth lumbar to first sacral interspace, and three in the third to fourth lumbar interspace. In one case the lesion was multiple.

The number of patients is small, as it is our practice to do myelograms only on patients who are to be operated upon. Thirteen patients improved remarkably with bed rest and traction. In four, surgery was withheld, as this was the initial attack. In seven others, the surgeon felt that the pain at the time of examination was insufficient to warrant operation. Four patients refused surgery. It may be pointed out that this group represents a cross section of patients more handicapped than would ordinarily be treated non-operatively, as surgery was anticipated in all.

RESULTS

The results in this series are viewed in relation to material from a prior study conducted in this Hospital[4], in which ninety-five patients were examined one to five years after removal of the lumbar intervertebral disc. In both of these investigations the patients were studied under the following groupings:

1. *Pain-Free*

This indicates that the patient is at present working, is completely free from symptoms, and that such an asymptomatic period is of more than one year's duration. Usually it indicates that the patient has been well since his hospital stay,—often considerably longer than a year. In spite of the absence of complaints, however, all of these patients cannot be considered to have normal backs; both those with and without surgery have been reluctant to engage in any strenuous activity, and they often demonstrate anxiety about future attacks.

In the non-operative group, eight patients (29 per cent.) were in the pain-free category; in the operative group, fifty-seven patients (60 per cent.).

2. *Residual Pain*

In this category are patients complaining of some residual or recurrent backache, either alone or in addition to radicular pain. The pain ranges from occasional mild disturbances to severe unremitting backache and radicular pain. Of the twenty patients in the non-operative group who complained of residual pain, fourteen had backache plus radicular pain; two suffered only radicular pain; and four complained of backache alone. Those patients in this category with marked disability are considered separately. Many were satisfied with their status. Twelve patients in this category (60 per cent.) suffered occasional pain; the remainder complained of constant pain. Such residual pain most often

TABLE I

RESULTS IN THE NON-OPERATIVE AND OPERATIVE SERIES

	Patients Free from Pain		Patients with Residual Pain		Patients Dissatisfied	
	(*No.*)	(*Per cent.*)	(*No.*)	(*Per cent.*)	(*No.*)	(*Per cent.*)
Non-operative	8	29	20	71	9	32
Operative	57	60	38	40	12	13

is precipitated by fatigue, overwork, or a specific act of heavy lifting or twisting of the spine.

In the non-operative group, twenty patients (71 per cent.) were in this category; in the operative group, thirty-eight patients (40 per cent.).

3. *Dissatisfied Patients*

Under this heading are those with residual pain who are subject to severe, recurring attacks of back pain and radicular pain. Some of these patients lose time from work each year; others are unable to work. In this category, the average period of disability since the onset of the pain has been over seven years.

In the non-operative group, nine patients (32 per cent.) are dissatisfied; in the operative group, twelve patients (13 per cent.).

In eleven cases followed three or more years with non-operative therapy, the results paralleled those of the entire group. Of the four patients in the total group of twenty-eight who refused surgery, two were dissatisfied, while the other two were pain-free under conservative care.

TABLE II

EFFECT ON OCCUPATION

	Patients Changing Work		Number of Laborers	Laborers Changing Work	
	(*No.*)	(*Per cent.*)		(*No.*)	(*Per cent.*)
Non-operative	12	43	13	10	77
Operative	19	20	48	15	31

OCCUPATION

Twelve patients in this study (43 per cent.) were forced to change their type of work. Of thirteen laborers, ten (77 per cent.) sought lighter work. In the operative series, nineteen patients (20 per cent.) changed their work and fifteen of forty-eight laborers (31 per cent.) shifted to lighter work.

THE MYELOGRAPHIC DEFECT

Each defect in the oil column was classified as mild, moderate, or severe, depending upon the degree of encroachment of the disc. If less than half of the column was indented, this was regarded as mild. A defect of more than half the column was called moderate, while any protrusion which divided the column was called severe. There were fourteen (50 per cent.) mild defects, nine (32 per cent.) moderate, and five (18 per cent.) severe. As far as we could estimate, the size of the defect in the spinal canal as viewed in the myelo-

gram showed no relation to the severity or persistence of symptoms, or to the clinical course of the patient. Three severe defects occurred in pain-free patients, and five of the nine dissatisfied patients had mild defects. These myelographic defects are not fully indicative of the true size of the disc, nor do they accurately locate the site of origin within the interspace. There is no reason to believe that the compression from the disc remains static. The occurrence of multiple acute attacks in many patients is oblique evidence that changes do occur.

CLINICAL FINDINGS

There are no definite features in the clinical examination which enabled us to prognosticate which patients would be relieved by conservative therapy and which would suffer repeated attacks. Patients complaining of pain at the time of follow-up examinations demonstrated some or all of the findings indicated. Those who were pain-free presented occasional atrophy, as well as reflex and sensory changes. In 30 per cent. of this series the reflexes, which had been diminished or absent at the time of hospitalization, were fully regained.

DISCUSSION

Spine fusion combined with disc removal has been favorably reported by Barr. The combined operation resulted in a significant decrease of residual pain, both in the back and in the extremity. We know of no report in which spine fusion alone was performed on patients with clinical and myelographic evidence of disc protrusion, although we have the impression that, preceding popularity of the "disc syndrome", freedom from pain was achieved by the fusion operation in some cases of this type.

The diagnosis of herniated intervertebral disc is being made more frequently. It is commonly thought that this disease undergoes healing by natural processes in a large majority of non-operative cases. Conservative treatment is intended to assist such healing by minimizing those stresses that provoke symptoms. This study confirms our impression that, whenever the extruded mass has reached a stage where it can be visualized by myelogram, the prognosis under non-operative therapy is poor. Some of the patients now free from pain can expect further difficulties.

In this study, 57 per cent. of the patients have been intermittently disabled for five years or longer. If a reparative process occurs, it is time-consuming and robs the patient of many years in the productive span of life. Perhaps the more optimistic reports of conservative therapy are engendered by observation of an earlier stage in this syndrome. Perhaps, also, other conditions with a more favorable prognosis have been diagnosed as herniation of the disc.

Kirstein followed forty-nine cases of ruptured intervertebral discs. Each of his patients had a positive myelogram; but in only seven of these myelograms was oil employed, while oxygen was used in the remainder. The cases were followed from six months to three years. Twenty-five of the forty-nine patients were operated upon. Of the twenty-four treated conservatively, 12.5 per cent. were free from pain; 48 per cent. of the patients in his operative group were asymptomatic. In this study, 28 per cent. were pain-free. In a previous report from this institution[4], 60 per cent. of the patients operated upon were free from pain.

Dunning followed fifty-five patients having the older diagnosis of sciatic neuritis, and under conservative treatment. From the clinical records of these patients, he made a presumptive diagnosis of herniation of the disc. No myelograms were done. Thirty-six per cent. of his patients were pain-free and 18 per cent. suffered mild discomfort; 46 per cent. were classified as unsatisfactory. Dunning's series must have contained many cases in which the myelograms would have been negative, and this would make it doubtful that his total number of cases represented patients with herniation of the disc.

SUMMARY

1. Twenty-eight patients with the clinical diagnosis of displaced lumbar intervertebral disc, supported by oil myelography, were treated non-operatively and followed.

2. Twenty-nine per cent. remained pain-free for periods longer than a year; 39 per cent. suffered insufficient residual pain to cause disability; 32 per cent. were disabled by recurring attacks or constant pain.

3. The results in this series compare unfavorably with the results obtained in a carefully selected operative series.

4. The chronicity of this disease must be fully appreciated; most of these patients had suffered five years or more. There can be little justification for letting the disease run its course.

5. No evidence has been found by which the course of the condition may be forecast.

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DISCUSSION

(*Continued from page 613*)

Osteomyelitis is an inevitable occurrence of the indiscriminate or indiscreet use of external pin fixation. I use such technique in a few selected cases.

Dr. D. C. McKeever, Houston, Texas: The remarks I wish to make concerning the use of external skeletal fixation are based upon experience with a method which I think is too frequently condemned without adequate trial. While in the Service, I saw a large number of compound fractures of the long bones. At one time, in a ward of 120 beds, all of the men had compound fracture of the femur. In no case was the limb in traction or in plaster. All patients except those with double compound fractures of the femur were walking with the aid of crutches. In other wards in the same hospital other methods of treatment were used, and there was adequate opportunity for comparison.

There is no question in my mind that the best initial treatment for compound fractures of the shafts of long bones is external skeletal fixation. It cannot be used by everyone. Before this method is attempted, one must have extensive knowledge of anatomy and mechanics, some degree of manual dexterity, and understanding of the principles involved in fracture treatment. All open reductions and most closed fractures should have constant pressure bandages applied, in addition to the skeletal fixation. I am not advocating this method in simple fractures, unless a large number must be treated quickly. I believe that this method is the best one for handling quickly a large number of compound fractures of long bones. Some form of apparatus for external skeletal fixation should be in the armamentarium of every orthopaedic surgeon. The Stader and the Roger Anderson type of apparatus were compared in a large number of cases. The Roger Anderson type is more adaptable to difficult cases and is much easier to use.

OSTEOCHONDROMATOSIS *

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Osteochondromatosis is a condition in which cartilaginous and osteocartilaginous bodies are formed within and by the synovial membranes of joints and, occasionally, of bursae and tendon sheaths. Synonyms include chondromatosis, synovial chondromata, joint chondromata, and diffuse enchondroma of the joint capsule.

ETIOLOGY AND PATHOLOGY

Most authors believe that trauma contributes in some degree to the formation of these bodies. The stimulus of a chronic inflammatory process, such as rheumatoid arthritis, has been suggested often. Many believe that the origin is from embryonic rests of primitive cartilage. The presence of cartilage has been demonstrated in normal synovial membranes. The hypothesis of origin which has been most widely held in recent years is that of benign neoplasm, no evidences of metastasis or local infiltration being found. Ewing's definition of tumor as "an autonomous new growth of tissue" is compatible with this hypothesis.

Jones, in 1927, showed microscopically that the formation of these cartilaginous and osteocartilaginous bodies follows the same stages that occur in the embryonic formation of cartilage, as described by Keibel and Mall. The cartilaginous bodies arise in the synovial membrane, directly from the fibroblasts (Fig. 1) or from the lining cells, which are modified fibroblasts (Fig. 2). The bodies usually arise in the stratum synoviale, rarely in the stratum subsynoviale. As they grow, they usually become calcified and ossified, fat cells but no myeloid elements being seen between the spicules of bone. Occasionally bone may form directly from fibroblasts (Fig. 3). As the bodies increase in size, they may be forced to the surface to become pedunculated (Fig. 4). When the pedicles break, as they frequently do, the bodies become avascular and the bone in them dies. The cartilage cells near the surface live, nourished by the synovial fluid (Fig. 5). The loose bodies are white, round or oval, with a smooth or faceted surface. In number they vary from a few to hundreds.

The synovial membrane in an involved joint may be thickened and villous. The vascularity is increased, and focal collections of lymphocytes may be seen microscopically (Fig. 6). Bodies which were previously free may become encysted in the membrane (Fig. 5), and deep-lying bodies may be palpated.

The process is apparently self-limited. Fisher wrote in 1921 that the condition may cease "as suddenly and as mysteriously as it commences". Freund stated that there is often a gradual decline and even a disappearance of the joint bodies. Faber and Bibergeil reported similar findings.

One patient in the series reported here underwent two operations, one week apart, one with an anterior and the other with a posterior approach, for removal of more than 100 loose bodies of a hip joint, and there was evidence of the production by the synovial membrane of more. Figure 7-A shows the preoperative roentgenogram. The surgeon had been unable to remove all of the loose bodies (Fig. 7-B), even with the second procedure

* Abridgment of thesis submitted by Dr. Mussey to the faculty of the Graduate School of the University of Minnesota, in partial fulfillment of the requirements for the degree of Master of Science in Orthopaedic Surgery.

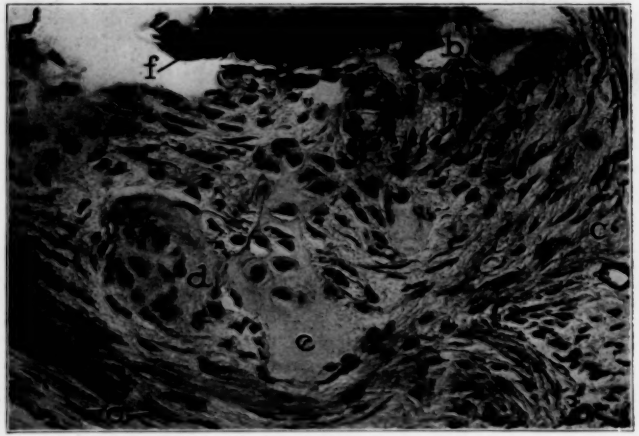

FIG. 1

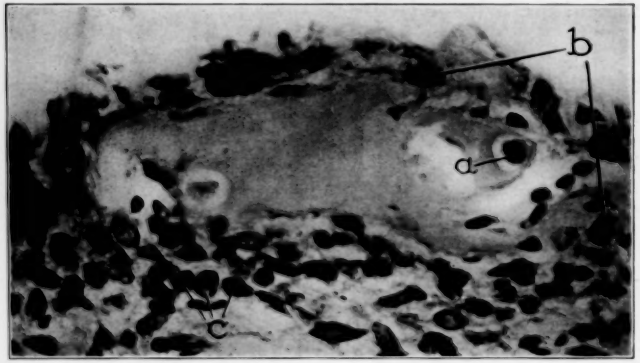

FIG. 2

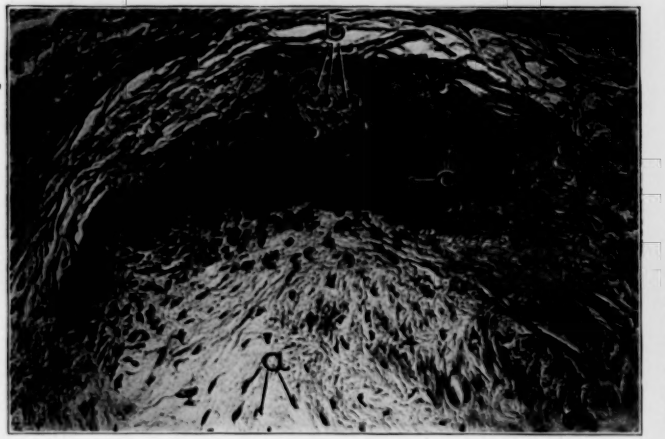

FIG. 3

Fig. 1: Fibrous-tissue cells (*a*) seem to be assuming a more rounded appearance (*b*). The matrix is becoming looser and more fibrillar (*c*). The cells become encysted in the matrix, which in some areas still retains a fibrillar structure, despite being partially hyaline (*d*). Some mature hyaline cartilage is seen (*e*). One area of calcified cartilage is present (*f*) (× 235).

Fig. 2: This section (× 400), taken from the tip of an elongated, vascular villus, shows an area of cartilage surrounded by lining cells of the villus. The encysted cell (*a*) and the cells becoming encysted (*b*) are indistinguishable from the lining cells (*c*). New cartilaginous matrix appears to be forming at both ends of the cartilage, in close conjunction with the lining cells.

Fig. 3: Stromal cells (*a*) enlarging (*b*) and forming bone directly, no cartilage being present. Some of the cells (*c*) have become encysted in bone (× 200).

FIG. 2

(× 200).

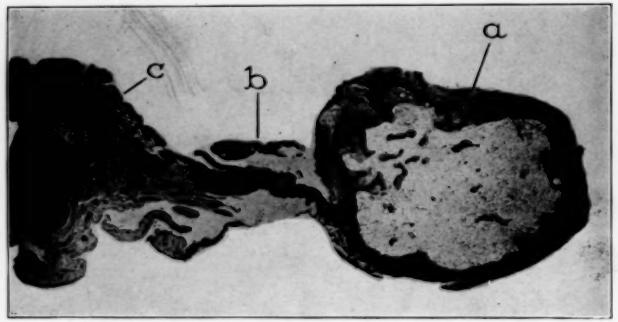

FIG. 4

Fig. 4: The osseous body (*a*) is connected by a pedicle (*b*) to the synovial membrane (*c*) (× 8).

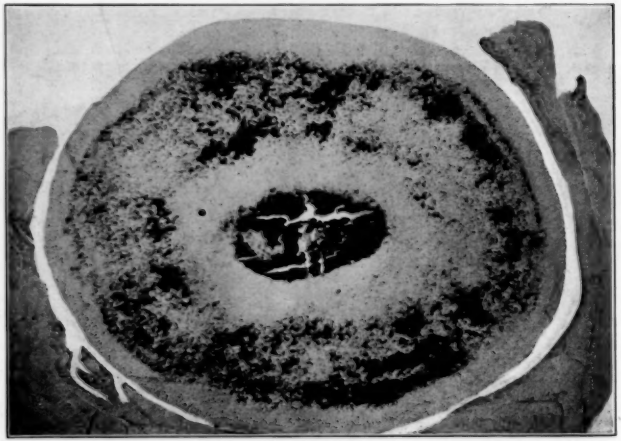

FIG. 5

Fig. 5: This avascular body (× 15) is seen encysted in synovial membrane. The only living cartilage cells are at the periphery of the body; the rest of the body is dead. The dark areas are deposits of amorphous calcium.

FIG. 6

This very vascular synovial membrane (× 40) contains six cartilaginous bodies, one of them very small. One (*a*) has thin connections with the large bone-containing body (*b*), which disappear in serial sections. New cartilage is forming from fibrous tissue at *c*. A focal collection of lymphocytes is present (*d*). The inner surface of the synovial membrane is particularly rich with blood vessels (*e*).

FIG. 7-A

Multiple calcified bodies may be seen around the hip joint before operation, along with spurring of the femoral head and narrowing of the joint space.

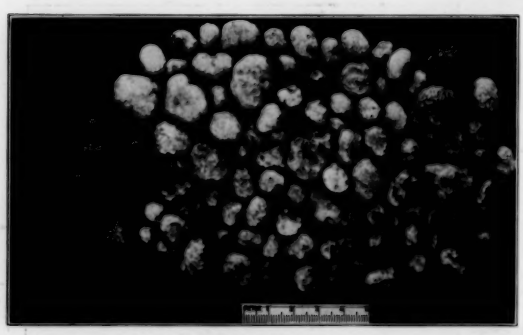

FIG. 7-B

Multiple loose bodies are seen, with a piece of the synovial membrane which contains calcified bodies.

(Fig. 7-C). Seven months later, only one faint calcified area remained (Fig. 7-D). A shallow acetabulum and a misshapen femoral head were present. Since this patient did not obtain a satisfactory functional result, more than four years later a Vitallium-cup arthroplasty was performed for relief of pain and for improvement of motion. At that time only a very few small, non-calcified, pedicled bodies were found.

Osteochondromatosis occurs more frequently in males than in females and is usually monarticular. The knee joint is involved most frequently, with the elbow second. Other joints, affected more rarely, are the hip, shoulder, wrist, ankle, temporomandibular, metacarpophalangeal, and interphalangeal. Bursae and tendon sheaths are seldom affected by this condition.

SYMPTOMS

The symptoms—weakness, aching, and progressive limitation of motion—are vague and chronic in type, and they vary according to the anatomical structure of the joint involved. Later, catching or locking may occur, although it is usually of a transitory

nature, followed by slight effusion, pain, and stiffness. There is rarely spontaneous pain, except with an episode of locking. A few patients mention that they can feel movable masses.

FINDINGS

Physical findings vary with the joint involved and with the degree of involvement. The joint may be normal to examination. Loose or fixed bodies may be felt. The joint capsule may be thickened somewhat, with moderate effusion. The motion of the joint may be decreased, although usually not markedly.

The roentgenographic picture varies with the stage of formation of the bodies and with their numbers. Calcification usually appears late and is generally not present in all of the bodies. Freund mentioned a patient who had an involved hip from which 395 radiolucent bodies were removed. If the condition has existed long, osteo-arthritic changes may be seen, unless masked by the bodies.

DIFFERENTIAL DIAGNOSIS

In typical cases in which large numbers of bodies are demonstrable by roentgenogram or during surgical intervention, the diagnosis is obvious. Rice bodies (corpora oryzoidea), associated with chronic infections such as tuberculosis, are differentiated with ease microscopically and with relative ease on the basis of history and findings. When there are few bodies, the differential diagnosis may become difficult, because loose bodies may be pro-

FIG. 7-C

FIG. 7-D

Fig. 7-C: A few calcified bodies may be seen around the inferior aspect of the femoral neck in the postoperative roentgenogram. One is present above the superior spur on the femoral head. The presence of a shallow acetabulum and a deformed femoral head should be noted.

Fig. 7-D: Little residual calcification is present. That above the spur appears increased in density, owing to a different photographic technique. Actually the roentgenogram showed a slight decrease of density of the body.

TABLE I

DISTRIBUTION OF AFFECTED JOINTS IN 104 PATIENTS

Joint Involved	Location			Total Number
	Right	Left	Bilateral	
Knee	36	30	7	73
Elbow	15	4	3	22
Hip	2	3	0	5
Ankle	1	1	0	2
Shoulder	1	1	0	2
Finger *	1	0	0	1
Totals	56	39	10	105 **

* Flexor-tendon sheath involved.
** In one patient, both an elbow and a knee were involved.

duced in osteo-arthritis, in osteochondritis dissecans, and occasionally after trauma. When the bodies are not radiopaque, the condition in the knee joint must be differentiated from a torn meniscus. The symptoms following a tear of the meniscus are more severe, particularly early in the condition.

Fisher, Smith, and Colonna all have written that a single body may be produced in osteochondromatosis. This is difficult to prove, for loose bodies of traumatic origin can become attached secondarily, as shown experimentally by Bloodgood, by Faber, and by Ito. Microscopic demonstration of a vascular body attached by a vascular pedicle should be sufficient to establish the presence of true osteochondromatosis (Fig. 4). In many cases, definite proof of diagnosis will not be present because the process in the synovial membrane may disappear completely, leaving one or more bodies and a normal membrane. However, a careful history and physical examination will clarify the diagnosis in a great number of cases.

TREATMENT

Unless otherwise contra-indicated, all accessible loose bodies should be removed from any affected joint, because of the mechanical articular damage they cause. In addition, synovectomy should be performed when the synovial membrane is seen to be producing more bodies. Only in the knee is it practicable to remove a large proportion of the synovial membrane, and even in this joint the posterior areas do not lend themselves to removal. It must be remembered that calcified bodies, easily seen on roentgenographic examination, may be found not to be within the joint at the time of surgical intervention because they are either in bursae, have not yet been liberated from the synovial membrane, or are encysted in pockets of synovial membrane within the capsule. The involved bursae, together with the bodies, should be removed.

RESULTS

Osteochondromatosis will not recur if the process has reached an end at the time of operation. If all loose bodies have been removed after the process is completed and before any secondary osteo-arthritis has become manifest, the result should be excellent. However, traumatic osteo-arthritis from the presence of the bodies is frequently present before the operation, and this will militate against a perfect result. Nevertheless, surgical intervention is indicated in these patients to stop further articular damage.

The end results relative to few patients can be found in the literature. Wilmoth reported postoperative examinations in seven of nine patients operated upon. In three there

TABLE II

RESULTS BY GRADES IN SEVENTY-NINE JOINTS, ACCORDING TO AGE OF PATIENT

Age at Operation (*Years*)	Number of Patients Followed	Grade of Joint			
		0	1	2	3
13 to 19	3		2	1	
20 to 29	16	1	2	7	8
30 to 39	10		4	3	5
40 to 49	13		4	8	3
50 to 59	23	2	4	4	13
60 to 69	7		4	2	1
70 to 76	1			1	
Totals	73	3	20	26	30

was no recurrence, in three the loose bodies remaining after operation were unchanged, and in one case the condition was essentially unimproved. No patient was traced more than four years after operation.

CLINICAL STUDY

The clinical records of all patients who had undergone operation at the Mayo Clinic from 1910 through 1945 for loose bodies in the joints or adjacent bursae were reviewed. All cases were included in the present study in which four or more loose bodies had been removed, unless these bodies were apparently secondary to trauma. Those patients from whose joints three or fewer bodies were taken were included only if there was a long history of disability, no definite trauma, and no hypertrophic changes roentgenographically; or if the synovial membrane, as seen during operation, appeared to be forming cartilage in any area.

One hundred and four patients were included in this study. Of these, twenty had been reported previously by Henderson and Jones or by Jones [10, 11]. Seventy-nine, or about three-fourths, were males. The average age at the time of their first operation at the Clinic was 42.9 years, eighty-eight patients being between the ages of twenty and fifty-nine years. The duration of symptoms, in the ninety-five cases in which this was recorded, averaged 8.3 years. The knee joint was chiefly involved (Table I).

Trauma was related by about half of the patients. One-half of the patients with affected elbows and one-third of those with affected knees recalled trauma. Five patients gave a history of an infection which might have been related to the condition. Pain, catching, locking, and episodes of "going out of joint" were prominent symptoms, and some of the patients had noted swelling, loose bodies, or a mass. Recurrent patellar dislocations had occurred in three cases. Six patients had had previous surgical intervention for the removal of loose bodies. Physical examination usually revealed decreased motion and, frequently, palpable loose bodies, masses, and enlargement of the joint.

Besides demonstrating the calcified areas or bodies, roentgenograms showed osteoarthritic changes in half of the joints. In six patients the corresponding contralateral joint was involved, although it was not operated upon.

At the time of operation it was noted that some of the bodies were attached by pedicles to the synovial membrane in one-third of the joints; hypertrophic changes were seen frequently. The synovial membrane occasionally appeared to be actively forming cartilaginous masses. Loose bodies were found in either true bursae or sacs, connected with the articular cavity, in twelve patients. Tendon sheaths were involved in two patients,—a finger-flexor sheath in one and the distal semimembranosus sheath in the other.

Partial synovectomy was performed on twelve articulations. Ulnar-nerve transfers were done for pressure symptoms in five elbows. Transfer of the patellar-tendon insertion was made in two knees. Arthrodesis was performed on two knees for marked destructive changes, and one extremity was amputated for an associated chondrosarcoma of the distal portion of the femur. One or two subsequent procedures were carried out on sixteen patients because of remaining or recurrent loose bodies, or ulnar neuritis. There were no postoperative infections or deaths.

In nine patients, an exostosis was noted in the affected joint. One of these patients also had fibroma of the thigh, and another concurrent carcinoma of the colon. A tenth patient, mentioned previously, had chondrosarcoma of the femur. One patient had definite and one possible osteochondritis dissecans in the involved joint. The hip joints of two patients presented shallow acetabula and flattened femoral heads.

Microscopic examination of the synovial membranes from eighteen joints revealed active formation of new bodies. Four of the eighteen had been reported previously by Jones [11].

Postoperative visits or written reports were obtained from seventy-three patients. The average follow-up period for these patients after the first surgical procedure was 8.5 years, with variations between one and thirty-two years. No case was included with a follow-up of less than one year. Two patients had died from unrelated causes, and one had died from associated chondrosarcoma. None of the seventy-three patients had had an operation subsequent to his surgical treatment at the Clinic.

In evaluation of the status at last report, four grades were employed. Those patients who said that they were unimproved were graded as 0. Those who were improved, but who had symptoms of any considerable degree or had suffered from subsequent locking, were placed in Grade 1. Grade 2 included those with minimal symptoms, such as mild pain after much use of the joint, mild limitation of motion, or discomfort with changes of weather. Those in Grade 3 had essentially no symptoms. Those in Grades 0 and 1 were considered to have unsatisfactory functional results, and those in Grades 2 and 3 to have satisfactory functional results. The age distribution of the traced patients and the results by grades according to age are seen in Table II.

There was no correlation between the number of surgical procedures and the postoperative result. There was a tendency for a better result in those patients who were followed a longer time after operation. Only four of the seventy-three patients complained of joint locking after operation.

Postoperative roentgenograms showed that calcified masses were present in eighteen patients, either in the capsule or loose in the joint. Of the fourteen of these eighteen patients for whom follow-up data were obtained, nine had satisfactory results and five had unsatisfactory results.

COMMENT

The etiology of osteochondromatosis cannot be stated definitely. This study does not support the hypothesis of infection. If the definition which Ewing uses is accepted, we believe this process to be one of benign neoplasm. An interesting finding is the coexistence of another tumor, usually an exostosis, in ten (9.6 per cent.) of the patients. This would suggest an individual tendency toward neoplasia.

The importance of trauma as a stimulus is, as always, debatable. Repeated slight traumata to a joint which transmits a great deal of force and which is relatively unprotected seem important. The distribution of affected joints tends to support this conclusion, for 70 per cent. were knees and 22 per cent. were elbows. Of the elbows, more than two-thirds were on the right. In addition, three-fourths of all the patients were males. The traumatic episode related by the patient probably served only to focus attention to that joint and thus allow establishment of the diagnosis.

The patient who had definite postoperative disappearance of calcification, with later surgical confirmation of the disappearance of the actual bodies, confirms the roentgenographic findings of Bibergeil, of Faber, and of Freund. This phenomenon was seen in only one of the 104 patients.

CONCLUSIONS

1. Osteochondromatosis is a benign condition, probably neoplastic, involving the synovial membranes of joints, bursae, and tendon sheaths, in which cartilage develops by metaplasia of the connective-tissue cells of the membrane.

2. Repeated slight traumata may well be an etiological factor, although infection probably is not.

3. There may be an individual predisposition toward neoplasia.

4. All accessible loose or pedunculated bodies should be removed surgically, because of the discomfort to the patient and the danger of secondary osteo-arthritis, which is a frequent complication.

5. If the process in a knee joint appears active in the synovial membrane at the time of operation, synovectomy should be done.

6. Unsatisfactory postoperative results are usually due to osteo-arthritic changes in joint-surface contours, and not to loose bodies.

7. Spontaneous disappearance of loose bodies may occur.

8. Negative findings on microscopic examination of the synovial membrane do not necessarily negate a diagnosis of osteochondromatosis, for the process may have completed its cycle and the membrane resumed its normal appearance.

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VITALLIUM-CUP ARTHROPLASTY OF THE HIP JOINT

An End-Result Study *

BY FRANK E. STINCHFIELD, M.D., AND ROBERT E. CARROLL, M.D., NEW YORK, N. Y.

Since Smith-Petersen first reported in 1939 the method of Vitallium-cup arthroplasty for treating diseased hips, many orthopaedic surgeons have used this procedure, with varying results, and other studies have been performed [2, 4, 7]. There is, however, a need to investigate completely and objectively the postoperative course of an unselected group of patients treated with Vitallium-cup arthroplasty. A study has been made of all the patients with various pathological conditions of the hip who received cup arthroplasty in one clinic. The purpose of this series is not to evaluate arthroplasty as a method of treatment, but rather to present an objective analysis of a group of cases in which it was used, and to show the course followed and the results obtained. It is hoped that this paper will stimulate other clinics or individuals to analyze and publish their results in like manner. Only in this way will enough data be accumulated to forecast accurately the course of recovery of patients having Vitallium-cup arthroplasty of the hip joint.

MATERIAL

At the New York Orthopaedic Dispensary and Hospital, forty-five cup arthroplasties have been performed on thirty-eight patients. Twenty right hips and twenty-five left hips were operated upon; seven patients had bilateral cup arthroplasty. Of the total number, twenty-nine patients (76 per cent.) had disease in both hips and nine (24 per cent.), in only one. There were twenty-six females and twelve males. The average age of all patients was 36.1 years; the average age of the females was 33.1 years and that of the males was 42.7 years. The youngest patient in the group was a six-year-old girl with congenital dislocation of the hip, but this case was not included in the average, as the age was so far out of line that it would have created a false average.

The group is not great, either in total or in the number of individual pathological conditions, but it represents the entire number of operations.

METHOD

The records of the patients were analyzed carefully and the pertinent information was recorded on a master chart; from this, the progress was followed. Range of motion, symptoms, and general functional results were recorded directly from hospital charts, and no deductions were made. To complete the study, the patients were recently interviewed and examined by the authors, the variations of multiple examiners thus being reduced to a minimum. The serial roentgenograms were reviewed and, when indicated, new films were obtained. In only 26 per cent. of the cases were the authors unable to evaluate the present condition of the patient. In these instances, the last clinical note closed the study.

Evaluation Criteria

The chief indications for surgery were pain and marked limitation of motion. In 76 per cent. of the cases, both hips presented some limitation of motion.

For purposes of analysis, it must be assumed that the operative technique was essentially the same; all operations were performed in the same Clinic, although by seven different surgeons.

The postoperative treatment was well standardized and consisted of:

* Presented at the Section on Orthopaedic Surgery, American Medical Association, Chicago, Illinois, June 24, 1948.

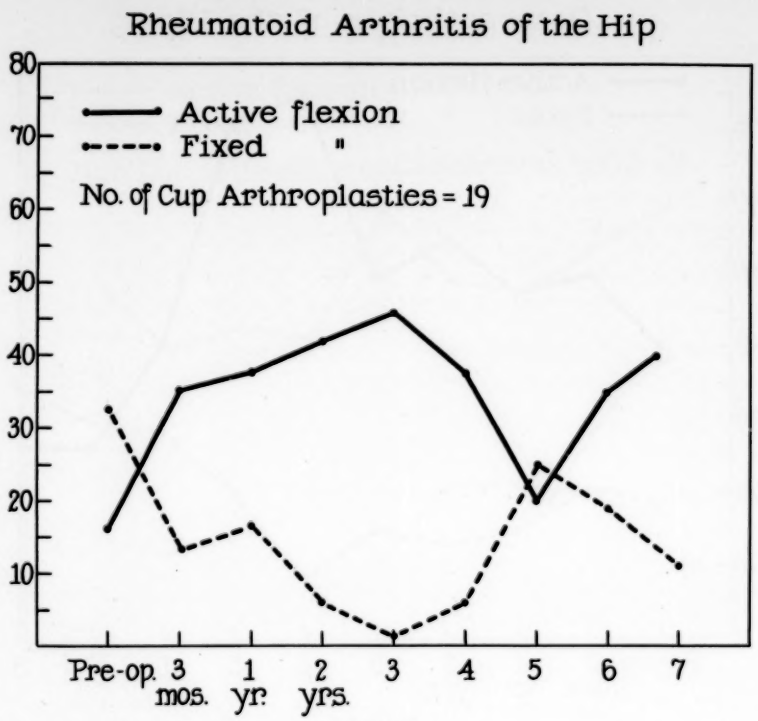

CHART 1

1. Traction-suspension for three weeks;
2. Roller-skating and active motion in a Hubbard tank, beginning at three weeks;
3. Use of a walker after three months;
4. Use of crutches after five months.

At a personal interview, the patient's evaluation of the amount of pain preoperatively and during each succeeding postoperative year was obtained. This was checked against the clinical record. To further evaluate the symptoms, the distance the patient could walk (with pain as the limiting factor) in the preoperative and postoperative periods was ascertained. The range of motion was measured in accordance with the standards described by Cave and Roberts. This is recorded in positive figures, which means that a hip with motion from 90 to 160 degrees has 70 degrees of active flexion, 20 degrees of fixed flexion, and obviously no extension.

The roentgenograms were evaluated in accordance with the criteria stated by Smith-Petersen[6] in his instructional course on arthroplasty of the hip.

End-Result Evaluation

A true evaluation of the results from this type of operation can be made only in relation to each individual case. No arbitrary standard can rightly be applied to all. Therefore, the evaluating standards used in this paper must be explained. The cases are classified as "very good", "good", "fair", or "poor" after having been analyzed according to:

1. *Motion:* The best case in the series, a patient with a five-year follow-up, had 5 degrees of fixed flexion, 95 degrees of active flexion, 30 degrees of abduction, 45 degrees of adduction, and 5 degrees of both internal and external rotation. This totals 180 degrees of active motion. This case formed the basis of criteria for evaluating motion.

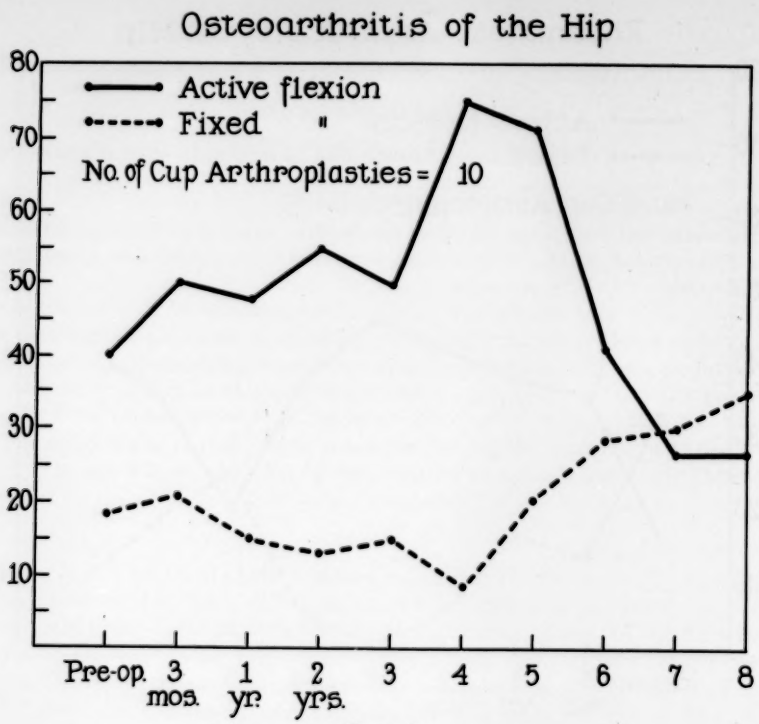

CHART 2

2. *Pain:* In this series, a good result means no pain at any time.

3. *Economic Status:* The patient's preoperative occupation was the basis upon which his postoperative result was judged.

ETIOLOGY

The cases fell into eight etiological groups, including rheumatoid arthritis, osteoarthritis, congenital dislocation, post-infection arthroplasty, slipped femoral epiphysis, arthrokatadysis, arthritis secondary to trauma, and osteochondritis dissecans. In analyzing these groups as to symptoms and physical findings, figures on range of motion were tabulated at preoperative observation, within three months after operation, and yearly thereafter. Although all patients did not continue to report regularly, the follow-up figures extend from one to eight years—from the first case done in May 1940, to the last in September 1947—the average being 3.22 years.

Charts 1, 2, and 3 indicate the average range of motion in different etiological groups. For purposes of clarity, only the degrees of active flexion and of fixed flexion were plotted. The other hip motions were in proportion to the active flexion.

Each case has been analyzed carefully. Time and space will not permit their illustration and evaluation individually, so they are being discussed here by etiological group.

Rheumatoid Arthritis

In sixteen cases of rheumatoid arthritis, Vitallium-cup arthroplasty was performed because of pain and limitation of motion of the hips. The average age in this group was 33.5 years. The known duration of the disease prior to surgery was 7.5 years, and the duration of pain in the affected hip was 3.7 years. Table I is a typical example of the factual data assembled from these cases. It will be seen from Chart 1 that in general

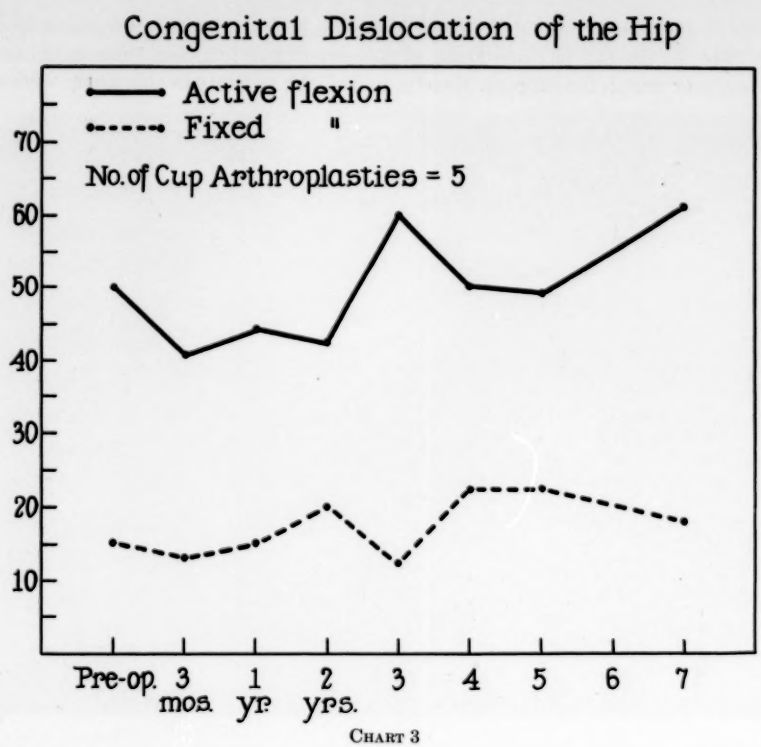

CHART 3

the hip motions, especially active flexion, continued to improve through the third year, after which the degree of motion gradually declined.

Twenty arthroplasties were done for rheumatoid arthritis. In one case the patient died six months after operation. The end results of the other nineteen were tabulated (Table II). Although these ratings were made primarily from the surgeon's standpoint, most of the patients were satisfied with their results. In general, a greater number received relief from pain than obtained good hip motion. Figures 1-A and 1-B show preoperative and postoperative roentgenograms of a case having a poor result. Figures 2-A and 2-B are similar views of hips showing a good result; the postoperative roentgenogram was taken seven years after the arthroplasty.

TABLE I

DEGREE OF MOTION BEFORE AND AFTER ARTHROPLASTY IN CASES OF RHEUMATOID ARTHRITIS

	Fixed Flexion	Active Flexion	Extension	Abduction	Adduction	Internal Rotation	External Rotation	No. of Hips
Before operation	32.5	16.2	0	5.2	2.9	1.9	2.5	20
After operation								
3 months	12.8	36.2	0	20.1	8.8	4.0	3.2	20
1 year	16.0	38.0	0	16.5	13.1	4.2	8.0	18
2 years	6.0	42.1	0	13.6	16.0	6.0	13.3	10
3 years	1.0	47.0	0	15.0	18.0	2.0	12.0	7
4 years	6.0	39.0	0	16.0	15.0	7.5	3.5	7
5 years	25.0	21.6	0	6.6	15.0	1.6	13.3	5
6 years	16.6	35.0	0	15.0	21.6	0	0	5
7 years	11.6	41.6	0	5.0	25.0	15.0	3.3	5

Four of the thirteen patients followed for one year after operation were using crutches at that time. At the end of three years, of the seven cases followed, three patients were using a cane or crutch for support. Exactly half of the patients in this group were using

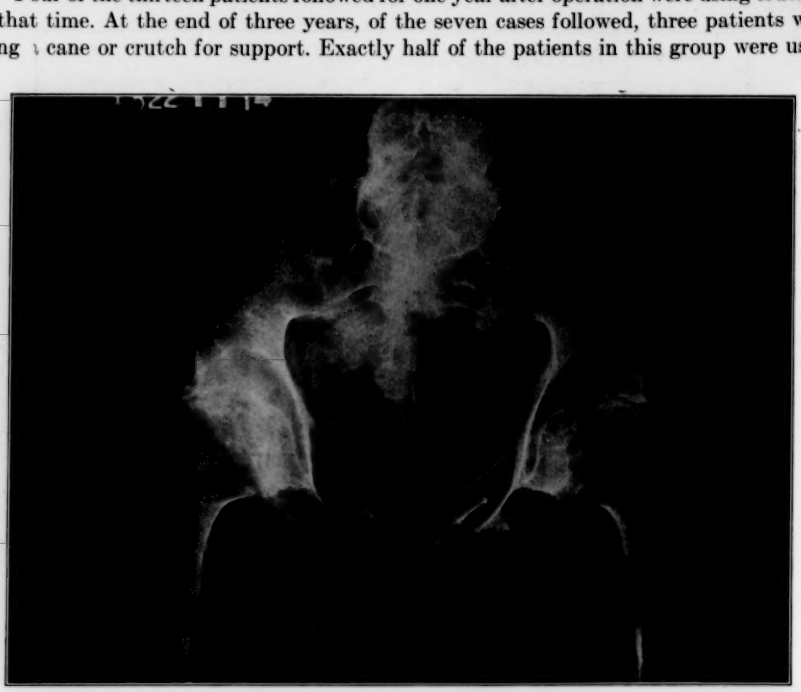

FIG. 1-A

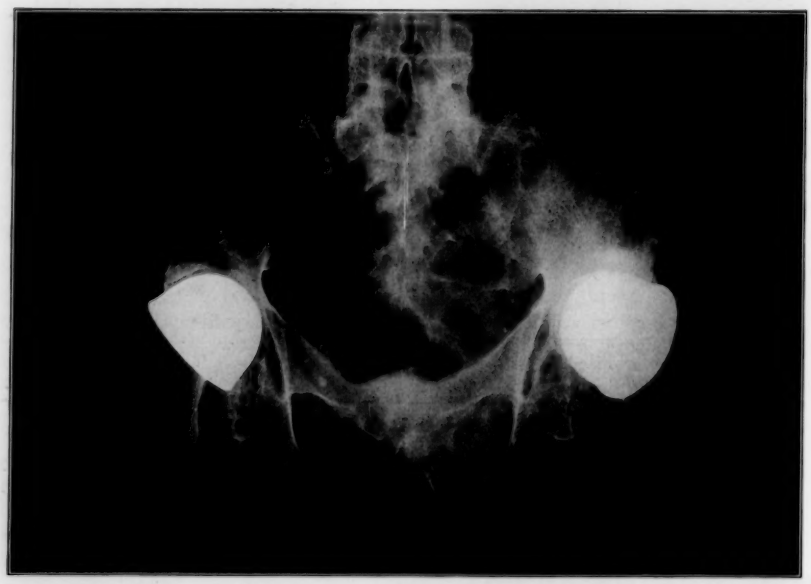

FIG. 1-B

Preoperative (March 22, 1941) and postoperative (March 16, 1948) roentgenograms of a case with poor results.

some kind of support when last seen. No correlation was found to exist between pain and motion. Although good results were not closely correlated with age, the two best results occurred in patients twenty-four years old.

FIG. 2-A

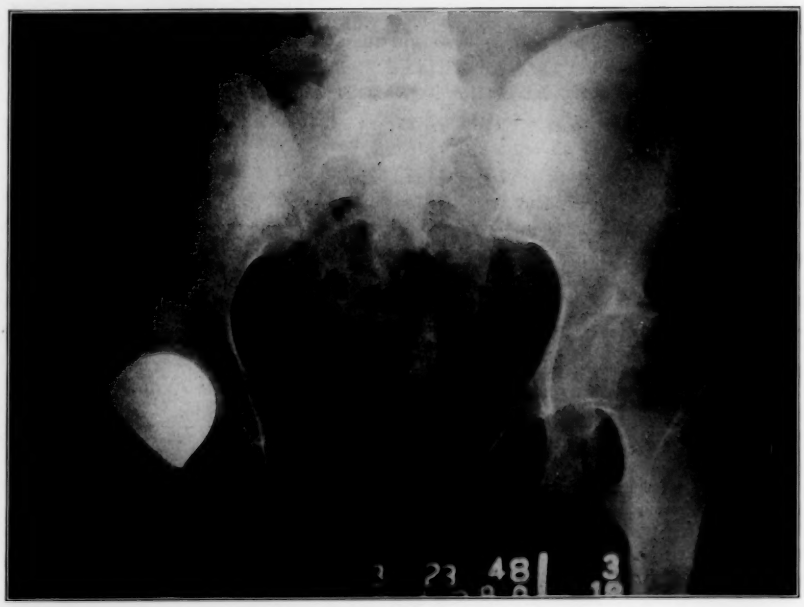

FIG. 2-B

Preoperative and postoperative roentgenograms. In this case the result was good, seven years after the arthroplasty.

TABLE II

RESULTS IN NINETEEN ARTHROPLASTIES * FOR RHEUMATOID ARTHRITIS

	Number of Cases
Motion	
Very good (180 to 115 degrees)	2
Good (115 to 80 degrees)	3
Fair (80 to 50 degrees)	8
Poor (50 to 0 degrees)	6
Pain	
None	8
Minimal	3
Moderate	6
Severe	2
Economic status	
Same job (no limitation of activity)	3
Same job (limited activity)	2
Sedentary occupation	6
No job	4

* Twenty arthroplasties were performed; one patient died six months after operation.

In three arthroplasties in this group, revision was required because of decreased motion and increased pain. In one case, trauma to the hip, two years after operation, caused a draining sinus of the wound. The cup was removed in this instance.

Osteo-Arthritis

Of nine patients upon whom ten cup arthroplasties were performed for osteo-arthritis, the average age was fifty-seven; the average known duration of the disease was 12.5 years; and the average duration of pain was 5.9 years. The indications for operation in cases of osteo-arthritis usually were pain; involvement of both hips, which contra-indicates arthrodesis; and stiffness in the lumbar spine.

In general, after surgery the motion increased until the fourth year and then declined somewhat (Chart 2). At that point the degree of fixed flexion deformity was the least.

TABLE III

END RESULTS IN NINE CASES OF OSTEO-ARTHRITIS ‡

	Number of Cases
Motion	
Very good (180 to 115 degrees)	2
Good (115 to 80 degrees)	3
Fair (80 to 50 degrees)	1
Poor (50 to 0 degrees)	3
Pain	
None	1
Minimal	5
Moderate	2
Severe	1
Economic status	
Same job (no limitation of activity)	2
Same job (limited activity)	5
Sedentary occupation	1
No job	0

‡ Ten arthroplasties were performed; one patient died eight days after operation.

TABLE IV

END RESULTS IN FIVE ARTHROPLASTIES OF THE HIP

	Number of Cases
Motion	
Very good (180 to 115 degrees)	2
Good (115 to 80 degrees)	1
Fair (80 to 50 degrees)	1
Poor (50 to 0 degrees)	1
Pain	
None	5
Minimal	0
Moderate	0
Severe	0
Economic status	
Same job (no limitation of activity)	3
Same job (limited activity)	0
Sedentary occupation	2
No job	0

These patients maintained their postoperative motion longer than any other group in this series, except for those with osteo-arthritis secondary to a slipped upper femoral epiphysis.

All of the nine patients with osteo-arthritis stopped using crutches at the end of one year. However, four of them, including one patient who had a bilateral arthroplasty, were using some form of support when last seen. The one patient whose condition was followed for eight years had to resume the use of crutches at the end of seven years.

The end results in this group are classified in Table III. No relation was found between pain and motion, or between motion and age. One patient, aged sixty-five, died on the eighth postoperative day as a result of pulmonary embolism from phlebothrombosis of the lower extremity. In one case in this group a revision of the arthroplasty was required, three months after operation, as it was feared that the cup would become dislocated.

Congenital Dislocation

The average age of five patients with congenital dislocation of the hip was 23.9 years; the duration of symptoms was 14.4 years; and the average duration of pain was 1.8 years. In this group the range of motion (Chart 3) continued to improve through the seventh postoperative year, although a slight degree of fixed flexion was still present.

These patients were satisfied with their results; none of them required a cane or crutches at the end of one year. At the end of two years, two patients required the use of a cane. One of the two patients whose condition was followed for seven years could walk about three miles without discomfort and without the use of support. Only one of the five patients required a cane at the time of a recent evaluation. As in the other groups, there was no correlation between pain, motion, and age. The classified end results are shown in Table IV.

One patient had a revision of her arthroplasty at the end of five years, as motion had markedly decreased and the roentgenograms showed increased bone proliferation. Another revision was required in a six-year-old child. At the end of two years the cup was removed, because it was found that the other structures had grown out of proportion.

Post-Infection Arthroplasty

Two patients having ankylosis of the hips due to previous infection were treated by cup arthroplasty; one case was bilateral. The average age of these patients was 19.5

years; the known duration of disease averaged 11.5 years; and the average duration of pain was 1.5 months. Although the group is small, the figures obtained show that motion was decreasing at the end of two years and that the amount of fixed flexion was increasing.

The patient who had a bilateral cup arthroplasty was still using crutches at the end of two years, but required no support when last seen. The other patient required neither

FIG. 3-A

Bilateral slipping of the upper femoral epiphysis.

FIG. 3-B

After cup arthroplasty, this patient had one of the best results in the entire series.

cane nor crutches at the end of five years, but was using a cane at the time of a recent interview.

The range of motion in these cases was poor, being below the total of 50 degrees. Pain was absent in two of the hips and only moderate in the other. Both patients returned to their previous sedentary work. Although the range of motion is poor, the patients are definitely improved, both as regards the amount of pain and the ability to earn a living. Revision was required in both of these cases, one at two months and the other at six months. New cups were placed, in order to give less pain and to allow a greater range of motion.

Slipped Femoral Epiphysis

Only two patients had cup arthroplasty for slipped femoral epiphysis. Their average age was thirty-one years; the known duration of disease averaged 18.5 years; and the average duration of pain was 1.3 years. The indications for surgery were pain and stiffness caused by osteo-arthritis, secondary to a slipped epiphysis. Motion increased through the third year, after which a decrease was noted. Neither patient required a cane or crutches after six months.

The end results in both patients in this group can be considered good by most standards, as motion was very good and there was no pain. Both returned to their previous occupations; one was a stenographer, the other a farmer. Neither has pain or limitation of activity, and neither required any revision.

A case of bilateral slipped femoral epiphysis (Fig. 3-A) had one of the best results (Fig. 3-B) in the entire series.

Arthrokatadysis

The one patient having arthroplasty for arthrokatadysis was eighteen years of age; the abnormality had been present since birth. She had fixed flexion deformity of both hips, but no pain.

A bilateral arthroplasty was done. Active flexion continued to improve, and the fixed flexion to decrease. At the time of last examination, the patient had a minimal amount of pain, but only fair motion in both hips; she required the use of crutches at all times. Her general condition has improved somewhat, but the result is not satisfactory to the patient.

Arthritis Secondary to Trauma

Two patients had arthritis of the hip secondary to previous trauma. Their average age was 27.5 years; the average known duration of disease was twenty-one years; and the average duration of pain was six years.

Although the follow-up is very short, the range of motion is increasing while the fixed flexion deformity has decreased. One patient had a very good result; he has an excellent range of motion without pain, and has returned to his duty as a farmer. The other has improved, but still uses a cane. He has a poor range of motion and is able to maintain only a sedentary job; pain is of moderate amount. This patient's cup dislocated four days after operation, so that an open reduction was necessary.

Osteochondritis Dissecans

The one case of osteochondritis dissecans occurred in a patient thirty-six years of age. The known duration of the disease and of pain was six weeks. An arthroplasty relieved the pain and allowed him an increasing amount of motion. The patient, a chronic alcoholic, had irregular living habits which affected the end result; however, he did achieve a fair amount of activity with the use of a cane. This patient was found in his room, dead of acute alcoholism, just four years after the operation.

DISCUSSION

The results in these cases are not surprising, in view of the indications for which the operation was performed. The majority of cup arthroplasties were done when the probability of arthrodesing the other hip was great. With such a high percentage of bilateral hip involvement, age did not make much difference. No patient died from the operation itself, although one death was due to a surgical complication, phlebothrombosis.

None of the patients upon whom cup arthroplasty was performed later had hip arthrodesis. Even a patient with a poor result from arthroplasty did not desire the arthrodesis. In three cases with poor results, the patients felt that the operation had not been worth while.

Although the most common indications for cup arthroplasty were pain and limitation of motion in the hip, the majority of the patients valued the relief from pain more than the motion.

The gait of patients with good range of motion was smooth. However, in all cases a limp was perceptible to the examiner. The use of a cane or crutch in walking was required in 45 per cent. of the cases. Of the seven bilateral cup arthroplasties evaluated, one patient used no support, one used one crutch, and the rest used two crutches for ambulation.

SUMMARY AND CONCLUSIONS

No definite conclusions can be drawn from a review of this number of cases, but the following impressions were received:

1. No correlation was found between age, motion, pain, and sex.
2. The results for the total group were not outstanding. When, however, individual cases were considered in regard to indications and postoperative course, the results were quite satisfactory.
3. Seventy per cent. of the patients were relieved of pain.
4. There is a definite period after operation during which the range of motion increases and the amount of fixed flexion deformity decreases. This occurs, in general, between the second and third years.
5. No patient in this series either had arthrodesis or wished to have it performed because of a poor arthroplasty result.
6. The best results occurred in patients having slipped femoral epiphysis. The poorest results were in patients with previous infection of the hip.
7. A series of cases of hip arthrodesis is being studied in exactly the same manner. From these two studies, definite conclusions as to indications and contra-indications will be drawn.

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AMPUTATIONS FOR FAILURE IN RECONSTRUCTIVE SURGERY*

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At Walter Reed General Hospital, one of the Army Amputation Centers, approximately 600 amputations were performed between October 1945 and October 1947. In this paper are discussed 250 in which numerous phases of reconstructive surgery had been performed during the preceding five years. In the remaining 350 cases not reported in this paper, the amputations were performed for reasons other than failure in reconstructive surgery,—such as for the treatment of primary vascular injuries and diabetic gangrene, incomplete traumatic severence, or malignant tumor.

The most apparent reason for this large number of reconstructive failures is that Walter Reed General Hospital is one of the last remaining Army Amputation Centers. The patients were transferred from other General Hospitals and from other services in this Hospital, when amputation was considered advisable.

The average period of reconstructive treatment from time of injury to amputation was well over two years, compared to an average of five and one-half months necessary for rehabilitation after amputation. The range was from four to sixty-eight months for reconstructive treatment, and from two to twenty-nine months for rehabilitation after amputation. The average age in this group of 250 patients was twenty-three years, few being outside the range of seventeen to thirty-five years. Two hundred and forty six (98.4 per cent.) of the amputations were of the lower extremity. The authors realize that the youth of this group, and the fact that the majority were lower-extremity amputees, aided greatly in obtaining favorable rehabilitation.

In spite of the advance and the improved techniques developed since the beginning of the First World War in plastic, orthopaedic, vascular, neural, and allied reconstructive surgery, surgeons doing this work should not lose sight of the proposed functional result or ignore the time necessary for the reconstruction. Since World War II, published articles have cited remarkable feats in reconstructive surgery, performed in military and civilian hospitals. The authors of these articles have sometimes neglected to show clearly the ultimate course in the cases which were functional failures,—those which finally came to amputation. The entire group reported here constitutes those seldom-mentioned failures.

Watson-Jones stated: "Amputation is seldom necessary in the treatment of bone and joint injuries, and the decision to adopt this unusual and drastic measure should always be supported by a second opinion. If the main blood vessels are not destroyed and there is no irrecoverable nerve lesion, the limb should be saved no matter how severe the contamination of a wound, the comminution of a fracture or the destruction of skin." The authors agree that the primary aim in the initial treatment in every case should be to save the injured extremity; however, we feel that, after the viability of the injured extremity has been maintained, the idea of "saving" the extremity, without regard for function, can be carried to an extreme that jeopardizes the welfare of the patient socially, mentally, and economically. For these reasons, one should not lose sight of the proposed functional result or ignore the time necessary for reconstruction.

The final decision on many cases, in which numerous surgical procedures had been done for repair of war injuries, had to be made by the staff of this Amputation Center after the case had been thoroughly studied, and after consultation with other specialists. It is

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†Released from active service.

difficult to lay down definite indications for amputation following failures in reconstructive surgery, as each case must be studied thoroughly from social and economic, as well as from mental and physical, standpoints. We shall, however, cite a few general indications.

REASONS FOR AMPUTATION

In a majority of instances, various combinations of infection and of injuries to bone, muscle, blood vessels, and skin were present, rather than injury to a single tissue. The authors have tried to arrive at the primary and secondary indications that influenced the decision to amputate.

Osteomyelitis

Amputation, as the treatment of osteomyelitis *per se*, is rarely advocated. In 111 cases (44 per cent.) of this group, however, long-standing, chronic osteomyelitis was the primary cause for amputation. Of these, 81 per cent. had associated bone defects, non-union, and structural deformity; 19 per cent. had nerve damage; 19 per cent. had circulatory impairment; and 67 per cent. had moderate to large skin defects superimposed on the bone infection. Of cases in which amputation was done primarily for other causes, osteomyelitis was present in 20 per cent.

The medical literature contains many enthusiastic reports of the treatment of osteomyelitis by means of saucerization, followed by the use of skin grafts, muscle grafts, and bone chips, as well as treatment by the Orr method, with or without antibiotics. The authors do not advocate amputation to replace these methods, which are effective in rehabilitating the patient in a vast majority of the cases that require such treatment, but cite some instances in which these treatments failed. In each amputation for chronic osteomyelitis, the patient had previously undergone recognized treatment with unfavorable results. Most of the infected areas had drained almost continuously for over two and one-half years, with little or no benefit from the procedures mentioned. The majority of patients in this group had had between three and fifteen sequestrectomies and saucerizations. Key and others have strongly advocated amputation in this type of case.

Bone Defect or Shortening

Although a bone defect or shortening of an extremity is not an indication for amputation, the importance of shortening is greatly emphasized when there is osteomyelitis, massive skin defect, or paralysis in addition to a bone defect. The condition may well be a primary indication for amputation. This fact becomes more apparent after prolonged treatment, when there is a probability of a poor functional result. Regarding this problem, Kirk has stated: "Persistent nonunion in bones of the lower extremity in the adult, particularly where there is marked loss of substance and when repeated autogenous bone grafts fail, must be considered an indication for amputation". Many of the authors' cases were in this group, osteomyelitis being the most prevalent cause of failure. In an extremity with several inches of shortening, associated with major skin, bone, nerve, and joint dysfunction, we believe that a well-fitting prosthesis is more efficient and less unsightly than a cumbersome built-up shoe. Sixty amputations (24 per cent.) were done primarily for large bone defects. Bone defects were a secondary cause for amputation in 117 (47 per cent.) of these war injuries. In forty-three (71 per cent.) of the sixty cases with large bone defect, there was associated osteomyelitis; in 50 per cent., a major skin defect; in 17 per cent., nerve involvement; and in 11 per cent., circulatory impairment.

Skin Defects

Patients were often transferred to this Hospital from Plastic Centers, where months or years had been devoted to attempts at skin-grafting a large area in preparation for reconstructive bone surgery of an extremity. Most of these cases showed failure after

FIG. 1-A

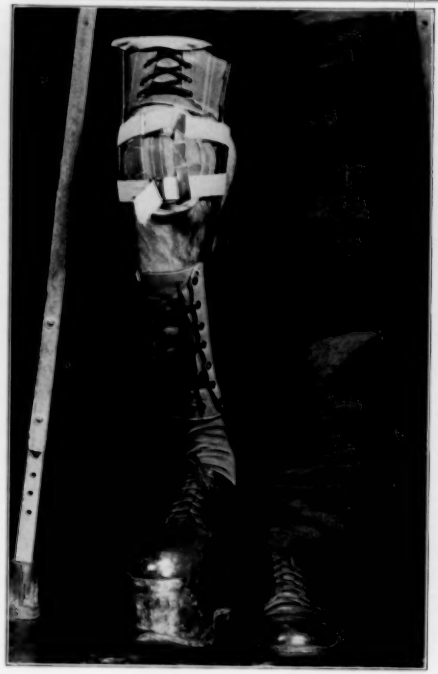

FIG. 1-B

FIG. 1-C

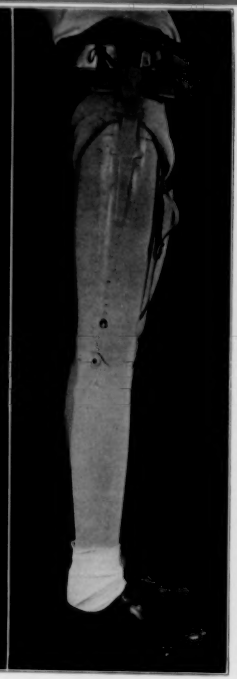

FIG. 1-D

Fig. 1-A: Massive destruction of the femur, five months after the patient had been struck by machine-gun fire. He received the routine treatment, consisting of débridement, antibiotics, hip-spica cast, balanced suspension-traction for one year, and numerous sequestrectomies because of osteomyelitis. The wounds about the knee were closed secondarily; and an arthrodesis of the right knee was performed one year after injury, a fibular graft being used. After eight weeks in a hip-spica cast, the patient was given an ischial-bearing brace; a built-up shoe was added five months later. Painful motion and drainage developed in the knee, and the patient was transferred to Walter Reed General Hospital.

Fig. 1-B: Ischial-bearing brace with shoe built up 4 inches (10 centimeters). Amputation was decided upon because of: (1) partial anaesthesia of the foot; (2) fibrous ankylosis of the ankle; (3) incomplete paralysis of the anterior group of leg muscles; (4) 5 inches (12.5 centimeters) of shortening of the extremity; (5) incomplete, painful fusion of the right knee; and (6) comminuted fracture of the lower third of the femur and its condyles, with persistent drainage from underlying chronic osteomyelitis.

A mid-thigh amputation was performed, twenty-two months after the injury.

Fig. 1-C: Shows patient after amputation and fitting with right-thigh prosthesis.

Fig. 1-D: Patient was able to wear his prosthesis as long as sixteen hours daily. If the arthrodesis had been successful and the osteomyelitis had been eradicated, he would have been left with an extremity 5 inches (12.5 centimeters) too short, a stiff knee and ankle, partial loss of sensation over the foot, and a cumbersome, heavy, built-up shoe. This combination is neither so functional nor so comfortable as a good above-the-knee amputation with a well-fitting prosthesis.

FIG. 2-A

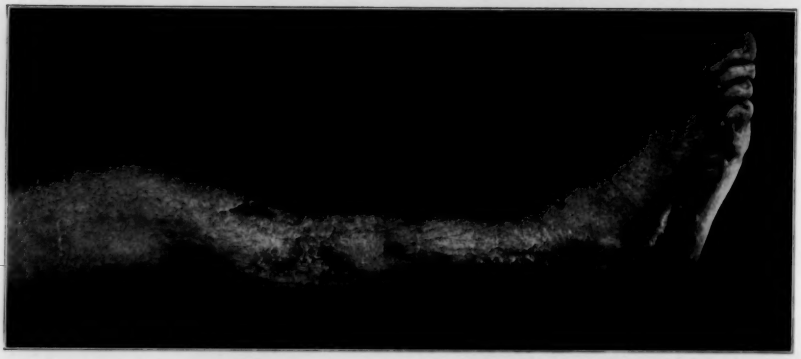

FIG. 2-B

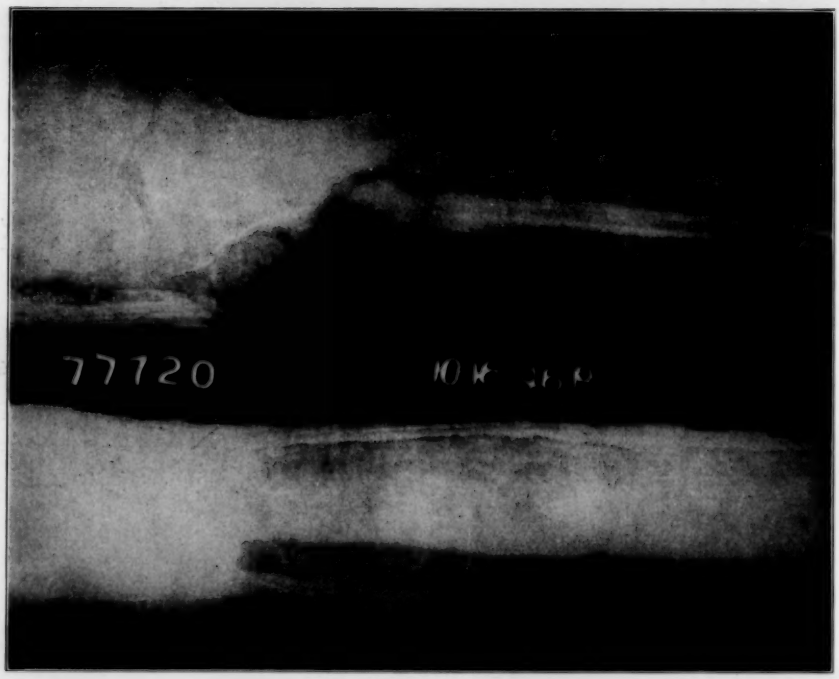

FIG. 2-C

Fig. 2-A and 2-B: This patient had sustained shell-fragment wounds of the right leg and knee, a compound fracture through the middle third of the right tibia, and incomplete section of the common peroneal nerve. Osteomyelitis developed and was treated by saucerization, followed by split-thickness skin-grafting, three months after the injury. The gap of 9½ inches (24 centimeters) in the tibia was bridged by transfers of the adjacent fibula, four and eight months later. Following the second transfer, the skin over the anterior surface of the leg sloughed. Pinch grafts were applied later with partial success. Osteomyelitis developed, with sequestration of the proximal portion of the fibular graft. Several sequestrectomies were done without improvement.

When the patient was transferred to Walter Reed General Hospital, eighteen months after injury, he had multiple draining sinuses and large skin defects with large amounts of scar tissue interposed, incomplete peroneal paralysis, a tibial bone loss of 24 centimeters, ankylosis of the ankle in moderate equinus, and 2 inches (5 centimeters) of shortening of the right leg.

Fig. 2-C: Roentgenograms taken through cast show massive tibial defect and unsuccessful fibular graft. More years could have been spent in reconstructive surgery in an effort to eradicate the infection, obtain good skin coverage, improve circulation and nerve function, and perform bone-grafting. The functional outcome would have been dubious, even had these procedures been carried out.

Fig. 2-D: Roentgenogram of stump after open amputation had been performed, just proximal to the area of osteomyelitis of the right tibia.

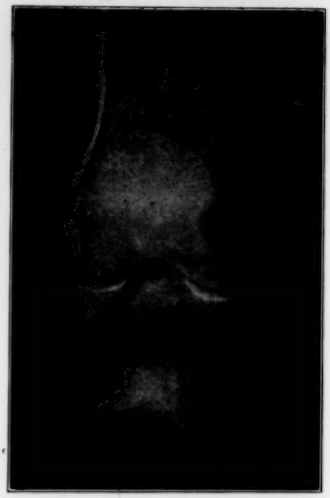

FIG. 2-D

FIG. 2-E

FIG. 2-F

Fig. 2-E: Short below-the-knee stump after plastic revision and healing.

Fig. 2-F: Prosthesis has an ischial weight-bearing thigh corset which carries most of the weight, leaving the short stump mainly for activation. With this short stump, the patient may require a bent-knee prosthesis or even a thigh amputation in future years. With the ischial-bearing prosthesis, however, his present stump should assure many useful years.

repeated attempts at pedicle grafts or full-thickness grafts. Many excellent grafts had finally to be discarded, due to the multiplicity of other indications for amputation. Much

FIG. 3-A

FIG. 3-B

Fig. 3-A: This patient was struck by shell fragments, receiving a laceration of the right popliteal artery with subsequent ligation. Ischaemic gangrene developed. Amputation was performed through the first, second, and third tarsometatarsal joints and through the bases of the fourth and fifth metatarsals, three months after injury. One month later, the granulating stump end was covered by split-thickness and pinch grafts. Seven months after injury, a tube skin graft was begun; this was completed in four months. After fitting with a special shoe, weight-bearing was attempted, only to be interrupted by drainage from the skin graft. Several sinusectomies, sequestrectomies, and sympathetic blocks were performed.

Photograph shows condition of foot upon arrival of patient at Walter Reed General Hospital, twenty-two months after injury.

Fig. 3-B: Roentgenogram of partial foot. Amputation at a higher level was advised because of: (1) marked equinus deformity; (2) inability to bear weight because of pain, even after several months' trial with a special shoe; (3) underlying infection; and (4) pressure necrosis of full-thickness skin grafts, without sensation, over weight-bearing areas. After lumbar sympathectomy, a modified or open amputation (done because of an infected field) was performed at the talonavicular and talocalcaneal joints, two years after the original injury. A routine Syme amputation was performed, six weeks later.

FIG. 3-C

FIG. 3-D

Photograph and roentgenograms of healed stump after Syme amputation.

time had, therefore, been lost, and the body had been marred by donor-site scars without commensurate functional gain.

Large full-thickness grafts on weight-bearing surfaces, especially on stumps of partial feet, are, in our opinion, of limited value. The authors followed twenty-two of these cases at Walter Reed General Hospital, in some of which the final grafting operation had been done two to three years before. Repeated ulcerations of these grafts occurred, in spite of

every effort to minimize pressure on the critical areas by furnishing the patient with a specially constructed shoe and with special brace attachments.

The indications for amputation of extremities with skin defects were:

1. Underlying pathological changes too extensive for repair, in spite of adequate skin-grafting;

2. Underlying pathological changes too extensive for repair, with inadequate covering of skin;

3. Repeated unsuccessful attempts at skin-grafting;

4. Unhealthy skin grafts on weight-bearing areas.

Absence of skin on an extremity was a primary reason for amputation in only 2.8 per cent. of the cases. In these cases, almost the entire extremity had been denuded; and several years of split-thickness grafting and pedicle grafting had left a paucity of donor sites, atrophied and scarred extremities, exposed painful nerves, fibrosed muscles, stiff joints, and a meager blood supply. Skin deficiency exercised a more important influence as a secondary indication for amputation, the problem existing to a fairly marked degree in 124 cases or 50 per cent. of this series.

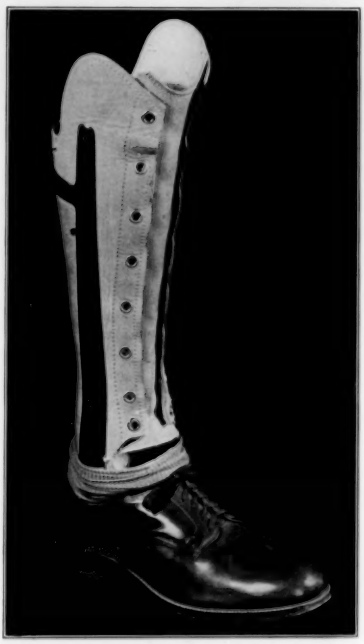

FIG. 3-E

Permanent type of prosthesis with which patient was fitted. He was discharged two and one-half months after the final amputation (twenty-six and one-half months after the original injury) with the characteristic painless, even gait. He was able to walk several miles a day and wore his prosthesis nearly all of his waking hours. It is easier to judge in retrospect; however, the authors believe that a Syme amputation should have been done nearly two years earlier.

Partial-Foot Amputations

Reconstructive surgery has definite limitations in partial-foot amputations. The only satisfactory partial-foot amputations of major proportion which the authors have seen on Army Amputation Services in the past four years have been metatarsophalangeal disarticulations and transmetatarsal amputations. The other commonly discussed amputations through the foot were not of so much functional value as those at the next higher levels,—namely, the Syme amputation or the below-the-knee amputation. The authors feel that the optimum functional amputation through the foot demands: (1) amputation distal to the bases of the metatarsals; (2) healthy plantar skin with minimum scar tissue, extending anteriorly over the end of the stump to the dorsal skin of the foot; (3) good nerve and blood supply to the entire plantar skin and skin flap; (4) function of the ankle and intertarsal joints, associated with strong leg muscles and negligible shortening of the extremity.

Partial-foot amputations, which were done in twenty-two (8.8 per cent.) of this group of 250 cases, have fallen into disrepute for the following reasons:

1. The essential tripod, formed by the calcaneus posteriorly, the heads of the first and fifth metatarsals anteriorly, and the great toe for balancing and walking, is lost or covered by scar tissue on the plantar surface.

2. Amputations through the foot at or proximal to the tarsometatarsal articulation have led to muscle imbalance. The insertions of the toe extensors—peronaeus longus, peronaeus brevis, and peronaeus tertius—and the major insertion of the tibialis anterior

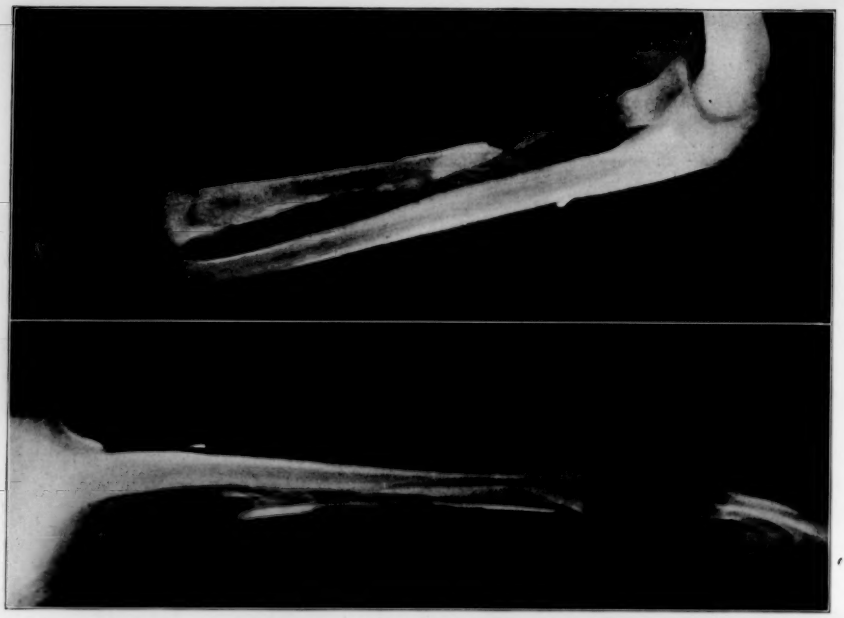

FIG. 4-A

Patient received flak wounds, sustaining a compound comminuted fracture of the right radius and severe injury to the ulnar, median, and radial nerves. Treatment in a prison hospital consisted of draining of abscesses of right forearm. These roentgenograms were taken after the patient's return to the United States, five months after injury. Physical findings were: multiple draining sinuses of right forearm; complete paralysis of radial and median nerves; and partial paralysis of ulnar nerve. The infection of the forearm subsided after numerous sequestrectomies, in addition to local and parenteral therapy. Eleven months after injury, the remaining distal radial fragment was fused at operation to the distal end of the ulna. Fifteen months after injury, the median and radial nerves were explored and found to be damaged irreparably.

FIG. 4-B

Condition of forearm and hand upon arrival of patient at Walter Reed General Hospital, two years after injury. Amputation was recommended because of: (1) complete absence of function of median and radial nerves and only partial function of ulnar nerve below the elbow; (2) irreversible atrophy of forearm and hand muscles; (3) fibrous ankylosis of wrist, hand, and finger joints; and (4) marked vascular changes throughout hand.

had been removed. This left the powerful posterior leg muscles unopposed, thus producing a marked equinovarus deformity of the foot. Although some still favor the Lisfranc amputation (namely, a tarsometatarsal disarticulation), the authors believe that the Lisfranc and Chopart amputations are of much less value from a functional point of view than the Syme amputation or the below-the-knee amputation. The Lisfranc, Chopart, and Pirogoff amputations should be considered as having only historical significance.

FIG. 4-C

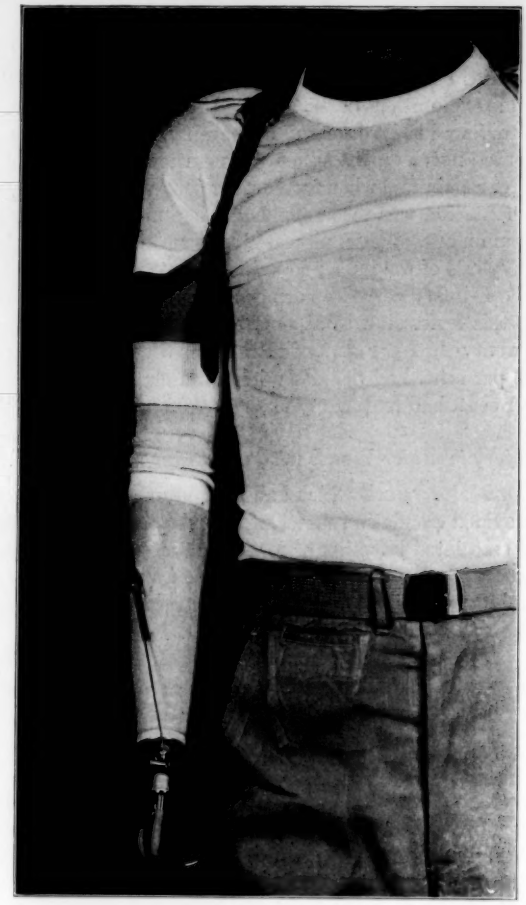

FIG. 4-D

Fig. 4-C: Healed below-the-elbow stump. Amputation was performed over two years after original injury.

Fig. 4-D: After toughening of the stump and strengthening of the arm and shoulder muscles, the patient was fitted with prosthesis. He was discharged four months after amputation (twenty-eight months after injury), capable of writing, handling tools, and caring for daily necessities. He was better satisfied with his functional hook than he had been with his useless hand.

The forearm, in the authors' opinion, should have been amputated as early as evidence of irrevocable nerve damage had been established.

3. When weight is borne on scarred, dorsal, or grafted skin with poor sensation—skin that is not accustomed to full weight-bearing—ulceration or painful callus formation results.

4. No prosthesis has yet been devised which will completely overcome the muscle imbalance and provide a coordinated and painless gait after the Lisfranc and Chopart procedures.

Some have advocated ankle fusion, triple arthrodesis, section of the Achilles tendon, tendon transplants, and full-thickness skin grafts in an effort to make partial-foot amputations satisfactory. In patients we have seen who had undergone these procedures, the pain and disability had not been relieved, and the full-thickness grafts became ulcerated, forcing the patients to spend most of their time on crutches or in wheel chairs. We feel that such time-consuming procedures, leading to functional failures, are contra-indicated.

Difficulty has been experienced in convincing some patients with an unsatisfactory partial foot that reamputation was needed. After a week or so of witnessing the facility with which Syme and below-the-knee amputees handled their painless stumps in well-fitted prostheses, these patients were convinced of the need.

Nerve Impairment

Amputation was frequently done for loss of nerve function, sciatic and brachial-plexus injuries being the most common. In such instances, the patients had undergone one or more explorations of the impaired nerve, when possible. Some nerves were repaired; others were found to be damaged irreparably. Joint ankylosis, fractures, and infection often prevented nerve repair. When regeneration did not occur within a reasonable length of time after repair, and when further neurosurgery was deemed inadvisable by the neurosurgeons, amputation was recommended. The authors consider a useful prosthesis more desirable than an anaesthetic, ulcerated, deformed, non-weight-bearing foot (or useless hand) with ankylosis of the knee and ankle and atrophied muscles of the leg and foot.

Primary nerve impairment accounted for forty-four (18 per cent.) of the amputations in this series; it was a contributing cause for amputation in 14 per cent. of the cases. Twenty-three per cent. of extremities with nerve impairment had associated osteomyelitis; 32 per cent. had definitely impaired circulation; 39 per cent. had bone defects; and 39 per cent. had reasonably extensive skin defects or trophic ulcers.

Injury to Major Vessels without Gangrene

Major vessels which had been injured without gangrene immediately resulting often provided circulation sufficient to maintain life in an extremity, but insufficient for healing of associated infection or for maintaining the part during or after reconstructive surgical procedures. In many cases, even after sympathectomy, the skin repairs, bone grafts, and arthrodeses failed; and the patients were left with pulseless, swollen, cold, hypersensitive feet and atrophic or ulcerated skin.

Although minor circulatory problems were present in a vast proportion of the 250 cases, blood supply figured strongly in the decision for amputation in only six cases (2.4 per cent.), secondarily in fifty-one cases (20 per cent.).

FINAL EVALUATION

After consideration of these factors, it is apparent that the decision to amputate should, when possible, rest on the opinions of several men experienced in reconstructive and amputation surgery, who have studied the individual case.

After surgical evaluation had been completed, the standard procedure was to ask the patient his desire and opinion. In rare cases, usually of upper-extremity injuries, the patient preferred a useless extremity to a useful prosthesis. No patient of this group had amputation without his full approval. Although some of the amputated extremities could have been saved by further extensive reconstructive surgery, the extremity would have been functionally not so valuable to the patient as a prosthesis.

The policy of the Army Medical Corps has been to return each soldier to active duty or to civilian life in the best possible physical condition, regardless of expense or length of treatment. This situation is ideal for reconstructive surgery. Even under these excellent conditions, however, the 250 patients in this group independently preferred amputation to a protracted hospital course with dubious results. Amputation, however, was by no means elected in all cases referred to us. Many patients thought severence of the extremity synonymous with a rapid termination of their difficulty. The authors did not hesitate to correct this delusion and to convince them that continuation of reconstructive surgery was important to their welfare, when a satisfactory functional result could be expected in a reasonable length of time. This group of patients did not have to be persuaded when the staff thought amputation advisable.

When prolonged treatment involves many of the most productive years of a patient's life and his own extremity, his viewpoint must be considered. It is difficult to manage an unwilling patient, undergoing full-thickness skin-grafting or encased in plaster. The pa-

tients who were most unwilling were those who had already been hospitalized for years, and whose outlook for functional recovery was still very doubtful.

Failures occur in amputation surgery, as in reconstructive surgery, and they should be prevented when possible. When amputation is indicated, the surgeon must select the proper type for the case being considered. Meticulous hemostasis and atraumatic technique in the handling of the freshly severed tissues[3] must be supplemented by preoperative and postoperative care, followed by physical therapy. The surgeon must have knowledge of the prostheses available, of their mechanics and function, and of the proper time to send the patient to be fitted[4]. He also must encourage correct early walking habits, if possible, and watch the condition of the stump in this critical period while the skin is still tender. If these principles are not observed, the amputating surgeon, like the reconstructive surgeon, will obtain poor functional or rehabilitative results. Our poorest rehabilitative results have been those necessitating hip and shoulder-joint disarticulations and high thigh and arm amputations, as prostheses for these amputations are still not satisfactory.

CONCLUSIONS

1. Amputation as an end result is better than a painful or useless extremity without hope of restored function.

2. The functional end result of extremity reconstruction and the time necessary to obtain this result must be kept constantly in mind.

3. Amputation in selected cases, when carried out in the proper manner, and when the limb is fitted with a correct prosthesis, should be considered a form of constructive treatment.

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A STUDY OF THE TENSILE STRENGTH OF THE MENISCI OF THE KNEE

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The frequency with which the menisci of the knee are injured and produce disablement has aroused the interest of clinicians in these seemingly insignificant structures.

On review of the various suggestions and explanations given in the literature, one realizes that the etiological factors in the highly frequent rupture of the medial meniscus are not fully understood. This view is further strengthened by the statement of Shands, Hutchison, and Ziv that "there is no one definite type of force or position of the limb associated with the displacement". The researches of Brantigan and Voshell have robbed the tibial collateral ligament of some of its importance in the causation of displacements and ruptures of the medial meniscus. These investigators have established the occurrence of one or two bursae between the ligament and the fibrocartilage, and the interposition of the true capsule of the joint between the two. According to Brantigan and Voshell: "The oblique portion of the tibial collateral ligament posteriorly is indistinguishable from the true capsule, and, accordingly, might be considered attached to the medial meniscus".

In the course of a study of the literature, the authors' attention was drawn to the facts that the two menisci, in their structure, have a fair amount of elastic tissue and that, because of the distribution of this tissue, the tears in the fibrocartilage are in the longitudinal axis rather than in the transverse axis. Interestingly enough, however, no reference could be found to the relative ability of the two menisci to resist sheering strains. This study, therefore, was undertaken primarily to determine the tensile strength of the lateral and medial menisci and to ascertain whether such information would throw any more light on the marked disparity in the incidence of rupture of the two fibrocartilages.

EXPERIMENTS

For this study, fresh menisci were carefully removed from amputated limbs. They were cleaned, and tags of adherent tissue were snipped off. The volumes of the menisci were determined by immersing them completely in a graduated tube, filled with normal saline solution.

To measure the tensile strength of the menisci, a simple apparatus was devised (Fig. 1). It consisted of a strong metal frame, three feet high, erected on a firm base. The horizontal bar on the top of the frame had a hook hanging from its center. The meniscus was fixed between two specially prepared metal clamps, by means of which it was suspended from the hook in the frame, as shown in Figure 1. From the free end of the lower clamp a rod with a circular plate at its bottom was suspended to carry the weights. Circular weights of one, five, ten, and forty pounds were made with a deep notch on one side to enable them to be put on the plate.

After a meniscus had been suspended, its length between the two clamps was measured and, as the weights were gradually added, the amount of stretching of the fibrocartilage was measured accurately. At the beginning and end of each experiment, care was taken to add a pound weight at a time, in order to prevent sudden stretching. When fracture of the meniscus occurred, the weights on the hanging plate and the type of fracture were recorded.

Attempts were made to ascertain the distribution of fibers of elastic tissue in a few of the medial and lateral menisci which were not fractured. The menisci were softened by keeping them in a 10 per cent. solution of sodium hydroxide for five days, and then in a 5 per cent. solution for two or three days. When they were soft, they were teased out, but satisfactory preparations of the elastic tissue in the fibrocartilages were difficult to attain.

Studies of tensile strength were also carried out on menisci obtained from twenty knees of dogs, for comparison with the menisci from human beings.

RESULTS

These studies have yielded interesting and significant data (Table I). Although thirty-three cases were studied, data on only thirty-two joints will be summarized, since in Case 1 only one meniscus was studied. In twenty-seven of the joints studied, the medial menisci were weaker than the lateral. In one joint the two menisci were equally strong, and in only four of the thirty-two joints were the medial menisci stronger than the lateral.

Of the twenty-seven joints in which the medial menisci proved weaker than the lateral, thirteen showed differences of more than twenty pounds (9.1 kilograms), and in at least three the lateral menisci withstood over forty-five pounds (20.4 kilograms) more than the medial meniscus. This is clear evidence of the structural weakness of the medial menisci, as compared to the lateral. The average reading for the medial menisci in this group at the time of fracture was about fifty-six pounds (25.4 kilograms), and that for the lateral menisci was seventy-four pounds (33.6 kilograms),—a considerable disparity.

The number of joints studied is not large enough to justify a full comment on the tensile strength of the menisci in the different decades of life, but the fact is clearly brought out that they become progressively weaker with age.

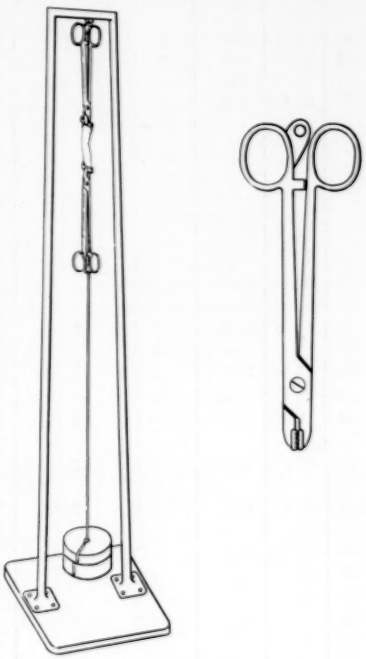

FIG. 1

Apparatus used to test the tensile strength of menisci.

The fractures occurring in the menisci when they were stretched were seldom transverse. In the majority of instances—twenty-one of the thirty-two medial menisci under consideration and twenty-four of twenty-eight lateral menisci in which fractures occurred—the fractures were either oblique or spiral. The tendency for a spiral fracture was more apparent in the lateral meniscus, probably because of the groove made in it by the tendon of the popliteus muscle.

The findings from the study on the menisci of dogs were interesting, inasmuch as in thirteen of the twenty joints the medial meniscus was weaker than the lateral. They were of equal strength in two, and in only five joints was the lateral meniscus weaker. In dogs, the fractures were usually transverse.

A consideration of the results leads us to believe that there is one more aspect to the question of the susceptibility of the medial meniscus to trauma. It is natural to think that the inherent strength and elasticity of the two fibrocartilages may be a factor of importance in the etiology of their rupture. Tobler is one of the few investigators in this

TABLE I

FINDINGS FROM STUDY OF SIXTY-FIVE MENISCI

Case No.	Age and Sex	Joint	Volume of Meniscus (*Cubic centimeters*)		Initial Length between Clamps (*Millimeters*)		Weight Needed to Produce Fracture (*Pounds*)		Type of Fracture	
			Medial	Lateral	Medial	Lateral	Medial	Lateral	Medial	Lateral
1	32 M.	Left			28		52		Oblique	
2	58 M.	Left			53	60	56	54	Oblique	Transverse at junction of upper and medial thirds
3	38 M.	Left			52	45	79	92	Oblique	Spiral
4	54 M.	Right			46	37	84	94	Oblique	Spiral
5	68 F.	Left	3.8	3.4	56	40	43	93	Oblique at junction of upper and medial thirds	Spiral
6	48 F.	Right	2.4	2.3	35	39	71	84	Oblique	Spiral
7	58 M.	Left	3.3	2.5	40	34	59	78	Oblique	Spiral
8	61 M.	Right	4.6	4.7	51	52	75	107	Transverse	Transverse
9	37 M.	Left	1.5	2.8	42	30.5	40	65	Oblique	
10	42 F.	Left	2.2	2.0	36.5	41	70	60	Oblique	Spiral
11	58 M.	Left	2.8	2.1	40	38	39	59	Oblique	Spiral
12	71 F.	Right	3.9	3.0	40	35	79	73	Transverse	Spiral
13	46 M.	Right	3.7	3.0	32	37	73	85	Fork-shaped	Oblique
14	75 M.	Right	3.7	3.8	59	46	18	63	At weak spot	Oblique
15	57 M.	Left	4.0	2.6	53	34	40	Slipped at 75	Almost transverse	
16	45 F.	Right	2.5	2.4	37	19	53	53	Oblique	Transverse
17	58 M.	Right	3.0	2.9	37	32	45	75	Oblique	Spiral
18	53 F.	Right	2.8	3.0	39.5	36	70	78	V-shaped	Spiral
19	M.	Right	4.2	2.5	52	48	58	Slipped at 77	Transverse	
20	75 M.	Left	4.1	3.0	47	43	47	79	Oblique	Oblique
21	63 M.	Left	4.5	3.0	63	39	44	57		Almost transverse
22	73 M.	Right	4.5	3.5	53	31	28	70	Transverse	Spiral
23	22 M.	Right	3.3	2.8	45	31	88	80	Oblique	Spiral
24	54 M.	Left	5.1	2.9	47	44	59	60	V-shaped	Oblique
25	61 F.	Left	2.0	2.3	30	32	39	70	Spiral	Oblique
26	81 M.	Left	4.8	4.5	48	35	60	64	Transverse	Oblique
27	19 F.	Right	1.7	1.9	32	31	65	80	Oblique	Spiral
28	73 F.	Left	4.0	3.2	55	39	54	59	Oblique	Oblique
29	32 F.	Left	3.2	2.8	50	36	72	88	Oblique	Spiral
30	78 M.	Left	3.8	3.4	52	43	45	67	Oblique	Oblique
31	17 F.	Right	2.9	2.1	40	37	60	Slipped at 82	Oblique	
32	10 F.	Right	3.1	2.8	38	35	43	78	V-shaped	Spiral
33	47 M.	Right	4.7	4.5	52	50	22	72	Oblique	Spiral

TABLE II

FINDINGS FROM STUDY OF MENISCI OF ANIMALS

Animal No.	Joint	Volume of Meniscus (*Cubic centimeters*)		Initial Length between Clamps (*Millimeters*)		Weight Needed to Produce Fracture (*Pounds*)		Type of Fracture	
		Medial	Lateral	Medial	Lateral	Medial	Lateral	Medial	Lateral
1	Right			12	12	50	50	Transverse	Oblique
	Left			11	12	47	48	Transverse	Oblique
2	Right			9	12	42	35	Oblique	Transverse
	Left			9	11	34	38	Spiral	Transverse
3	Right			12	12	34	25	Transverse	Transverse
	Left			11	12	32	29	Oblique	Transverse
4	Right			10	8	27	35	Transverse at junction of medial and lower thirds	Transverse
	Left			14	14	29	35	Transverse at junction of medial and lower thirds	Oblique
5	Right			12	15	31	23	Transverse	Transverse
	Left			9	11	35	25	Oblique	Transverse
6	Right			14	15	40	50	Transverse	Transverse
	Left			15	13	42	49	Transverse	Transverse
7	Right			11	12	36	51	Spiral	Transverse
	Left			12	14	21	46	Oblique at junction of medial and lower thirds	Spiral
8	Right			10.5	15	40	44	Oblique	Oblique
	Left			9.5	13	42	53	Transverse	Transverse
9	Right	0.5	0.7	12	15	49	56	Spiral	Oblique
	Left	0.5	0.7	13	15	43	54	Transverse	Oblique
10	Right	0.6	0.9	14	17	55	58	Spiral	Transverse
	Left	0.6	0.9	13	14	60	60	Spiral	Oblique

field who was impressed by the relation of the waviness of the elastic fibers to the elasticity of the fibrocartilages. He stated that this waviness of the elastic tissue is important in the understanding of the pathological changes, particularly in reference to their rupture. He further observed that, with the onset of the degenerative changes in the menisci, the wavy character of the elastic fibers is lost; the fibers become straight and often rupture.

It has been established by Tobler, Bennett and his associates, and others, that degenerative changes begin between the first and second decades of life. Considering the early appearance of the degenerative changes and their effect on the elasticity of the menisci, we can understand the occurrence of traumatic lesions of the structures in the second and third decades of life.

There is little doubt that in their normal functions the menisci, especially the medial one, suffer many stresses and strains. As Fisher has pointed out, they "assist the lateral ligament of the opposite side to resist undue lateral movement". Furthermore, in sudden inward twists or rotation of the femur on the fixed tibia, the medial meniscus is put under extreme tension. Obviously, the weak medial meniscus, rendered weaker by degenerative changes, would be unable to resist the strain. In view of these facts and of our own observations, it seems plausible that the inherent weakness of the medial meniscus, in association with its shape and structure, is as much responsible for the high incidence of its rupture as is its slight attachment to the tibial collateral ligament.

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RADIATION OSTEITIS OF THE RIBS

REPORT OF A CASE WITH FRACTURES APPEARING FOUR AND ONE-HALF AND ELEVEN YEARS AFTER THERAPY

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Radiation osteitis has received little mention in the literature. Only in recent years has the growing interest in this phenomenon been reflected by an increasing number of articles on radionecrosis of the mandible, the femoral neck, the ribs, and other skeletal structures.

Rib involvement by radiation osteitis does not entail the mechanical problems inherent in involvement of weight-bearing bones. However, the task of differentiating such sequelae from metastatic foci makes their recognition imperative. The purpose of

this paper is to present a case of radiation osteitis in which fractures of the ribs appeared four and one-half and eleven years, respectively, after the initial postoperative roentgenotherapy for carcinoma of the breast.

CASE REPORT

H. G., a white woman, forty-nine years old, was referred to the Wisconsin General Hospital on April 19, 1937, for radiation therapy following a radical left mastectomy, performed elsewhere on March 29, 1937. A Grade III carcinoma had been removed and axillary metastases were found. The patient had been conscious of pain and a lump in the left breast for only two weeks prior to surgery.

Using a technique described in detail by Pohle and Benson, postoperative roentgenotherapy was administered to each of four fields daily for eight treatments. The fields treated were the supraclavicular, anterior portion of breast, and anterior and posterior axillary regions. Similar courses of therapy were given in July and December 1937, in July 1938, and in February 1939. In all, a total dosage of 7,750 r (in air) was administered to each of the four fields treated during that period. The patient was well and free from metastases at the time of her last examination, January 12, 1948.

On September 30, 1941, radiation osteitis and pathological fracture of the anterolateral arc of the left fourth rib were found. A routine chest film on September 14, 1940, had been negative for metastasis or radiation osteitis.

In a group chest survey on December 30, 1947, the fracture which occurred eleven years following therapy was suspected of being a metastasis; the attending physician, who recognized the true character of the lesion, referred the patient to us chiefly for reassurance *. Our roentgenograms, taken on January 12, 1948, revealed partial healing of the previously discovered fracture in the fourth rib and the appearance of radiation osteitis and pathological fracture in the anterolateral arc of the left third rib (Fig. 2).

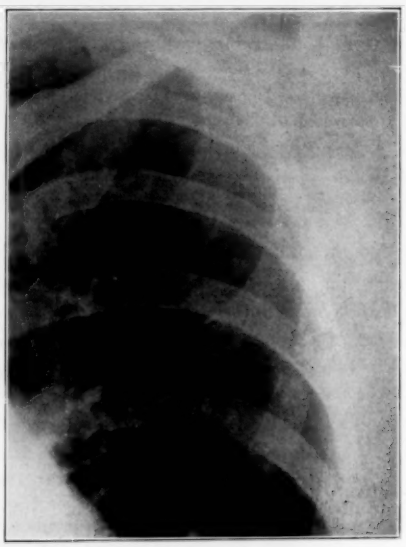

FIG. 1

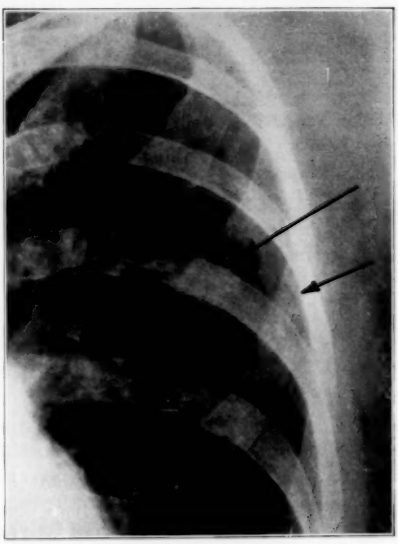

FIG. 2

Fig. 1: Roentgenogram taken on April 4, 1942, demonstrating radiation osteitis and pathological fracture of the anterolateral arc of the left fourth rib, changes which had been detected first on September 30, 1941.

Fig. 2: Roentgenogram of January 12, 1948, showing healing of the fracture in the fourth rib and appearance of radiation osteitis with associated fracture in the anterolateral arc of the left third rib. The third rib was not involved until eleven years after the initial therapy had been administered.

DISCUSSION

In a previous article on this subject by Paul and Pohle, the literature was reviewed and the roentgenographic findings were described. A detailed review will not be repeated, but a few comments are indicated.

* The last roentgenogram of the chest on file before December 1947, was taken on March 3, 1945, and was reported as negative.

Bone, even adult bone, can no longer be regarded as relatively insensitive to irradiation. Its calcium content results in increased absorption of rays entering it as compared to less dense tissues. Slaughter stated that, according to Failla, this increase amounts to 30 to 40 per cent. The mineral content also produces a greater amount of soft secondary radiation than is found in other tissues. Warren regards bone as more sensitive to irradiation than skin or mucous membrane.

As pointed out by Ewing, the extent of bone involvement varies from minimal reversible changes through sclerosis, fracture, and sequestration, to the most severe type in which secondary osteomyelitis occurs. The last is found most frequently in the mandible. Radiation osteitis is usually painless, except in mandibular cases with superimposed infection. When symptoms occur, they are most often due to mechanical disability arising from involvement of weight-bearing bones. Since rib involvement is almost always asymptomatic and painless, the fear of producing this complication should never interfere with the administration of an adequate course of therapy in breast carcinoma or other lesions of the chest wall where irradiation will involve the ribs.

Spontaneous healing of fractures due to radiation osteitis apparently depends upon the severity of bone involvement and the degree of obliterative endarteritis inherent in the process. Roentgenographically, the first change is the transverse irregular fracture line, appearing in the anterior or anterolateral arcs of the upper ribs. Malalignment may be present and the bones are usually osteoporotic. Bone sclerosis may appear later. In case of healing, the bones are increased in density.

Recognition of the true nature of the lesion is of prime importance. The absence of any history of trauma and the asymptomatic nature of the lesion distinguish it from a traumatic fracture. More difficult, and more important, is the differentiation from a metastatic focus. The transverse fracture line, almost constant location of the lesion in the anterolateral arcs of the third to the fifth ribs, slow progression, and tendency to heal either by bony union or eburnation of the ends of the fracture fragments, as opposed to the moth-eaten rarefaction or destruction seen in metastatic disease, aid in the differential diagnosis.

The time interval between therapy and the appearance of osteitis has not been reported adequately in the literature. It is becoming increasingly apparent that radiation osteitis is a lesion which may appear at greatly prolonged intervals following irradiation. Friedmann has reported a case in which rib fractures occurred five and seven years after the start of therapy for breast carcinoma. Therapy was administered before and after radical mastectomy, and several local metastases were treated within a period of three years. The total amount of irradiation, therefore, was far greater than usual.

Wammock and Arbuckle, using interstitial radium therapy for breast carcinoma and employing an average of 22,000 milligram-hours per patient, reported ten cases, all free of carcinoma for periods ranging from four to nine years, and all with rib fractures which appeared from eleven months to seven years after the start of therapy.

Eight cases of radiation osteitis, five with fracture of the clavicle and three with rib fracture as sequelae to therapy, are reported by Slaughter. The time interval between therapy and detection of osteitis in his cases varied from one to sixteen years. However, the time of onset of the complication was not determined, since the osteitis was usually an accidental discovery, no progress films having been taken at regular intervals. In the clavicular cases, those with a long interval showed evidence of long-standing involvement. Slaughter estimated that the ribs and clavicles received about 2,000 r.

Reviewing 2,046 cases of intracranial tumors, Camp and Moreton found five with aseptic necrosis of the calvarium. They did not regard this figure as the true incidence of the complication, since not all of the cases reviewed had an adequate follow-up. As with rib involvement, radiation osteitis of the calvarium is an asymptomatic process, and fear of its occurrence should not be a deterrent to adequate therapy. In their five cases the

longest interval between therapy and changes in the calvarium was twelve years, the time of onset being proved by intermediate films. In two cases with detection of the involvement at fourteen and seventeen years, the actual time of onset was not determined.

Hatcher reported a woman treated for breast carcinoma, following mastectomy, through anterior and lateral portals to the right shoulder. The quantity of irradiation was unknown, but no skin changes occurred. Eleven years later chest pain developed and, after further therapy, a chondrosarcoma of the anterior portion of the right seventh rib was resected. Although Hatcher believed the sarcoma to be related etiologically to the irradiation, we cannot but doubt such a relationship. The occurrence of bone sarcoma in therapeutically irradiated tissues is encountered so rarely that its occurrence could be considered merely coincidental. In addition, the anterior segment of the seventh rib receives only a small amount of irradiation with the usual techniques employed in the therapy of breast carcinoma. Most of our patients have shown the changes of radiation osteitis only in the third to the fifth ribs.

CONCLUSIONS

1. Radiation osteitis of the ribs associated with pathological fracture is a slowly developing lesion which may appear at varying intervals following initial irradiation. The eleven-year interval in the case presented is believed to be one of the longest reported in the literature.

2. Healing of such fractures may occur, but the process is very slow, as exemplified by the presence of only partial healing in one such fracture during a six-year observation period.

3. The importance of distinguishing radiation osteitis from metastatic carcinoma should be emphasized.

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THE TREATMENT OF NON-UNION OF FRACTURES OF THE MEDIAL MALLEOLUS

BY SAM W. BANKS, M.D., CHICAGO, ILLINOIS

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The purpose of this paper is to describe a bone-grafting technique for use in cases of symptomatic non-union of the medial malleolus. Not all pseudarthroses of the medial malleolus require treatment. A strong fibrous union with the fragment in good position may be compatible with full function of the extremity and may produce no symptoms. On the other hand, corrective surgery is indicated in the presence of disabling symptoms. These consist either of pain and swelling over the malleolus, an associated posterior tibial tenosynovitis, or instability of the ankle.

TECHNIQUE OF OPERATION

The bone is exposed subperiosteally and the deltoid ligament is isolated beneath the deep fascia. All fibrous tissue between the tibia and the malleolus is excised. The fragments are freshened so as to expose cancellous bone by removing the bone at the site of non-union in a wedgelike fashion, with the apex at the surface of the ankle joint and the base outward. This preserves a maximum amount of the articular surfaces. The fracture of the malleolus is reduced, and the bone is held by towel clips or tenaculum forceps while a metal screw, one and three-quarters inches long, is passed upward through the malleolus from its tip into the tibia.

The triangular defect between the malleolus and the tibia is packed with cancellous bone, obtained from the tibia through a window at the proximal end of the wound. A block of cortex, one and one-half inches square, is removed, as shown in Figure 1. The bone is undercut in such a way that the block will not fall into the medullary cavity of the tibia when it is replaced. The wound is closed in layers and a toe-to-knee cast is applied, with the foot in sufficient varus to relax the deltoid ligament.

POSTOPERATIVE CARE

The plaster is changed in fourteen days, when the sutures are removed, and a walking iron is incorporated in the new cast. Partial weight-bearing with crutches is permitted during the next two weeks, and full weight-bearing thereafter. Roentgenograms obtained from eight to ten weeks after the operation should show consolidation of the fracture; if so, the cast may be eliminated. Whirlpool baths, massage, and assisted active motion facili tate the final recovery.

Six patients have been treated successfully by this method. The following case reports are characteristic.

CASE 1. R. T., a male, aged twenty-seven, sustained a fracture of the medial malleolus and of the fibula at the junction of its middle and distal thirds, with lateral displacement of the right foot, on November 19, 1947, when a brick wall collapsed and fell onto his leg. A closed reduction was performed under general anaesthesia immediately after the injury; a plaster splint was worn for seven weeks. The patient returned to work on March 2, 1948, but was unable to continue after two weeks, because of severe pain and swelling over the medial malleolus.

The author first examined the patient on April 19, 1948. Physical and roentgenographic examinations (Figs. 2-A and 2-B) showed non-union of the medial malleolus with persistent slight lateral displacement of the foot. A cancellous bone graft was applied on April 21, and the malleolus was fixed by a metal screw. Roentgenograms (Figs. 2-C and 2-D), taken eight weeks later, showed union of the medial malleolus; at that time the cast was discarded. The patient achieved full painless motion of the ankle and returned to his job as a bricklayer.

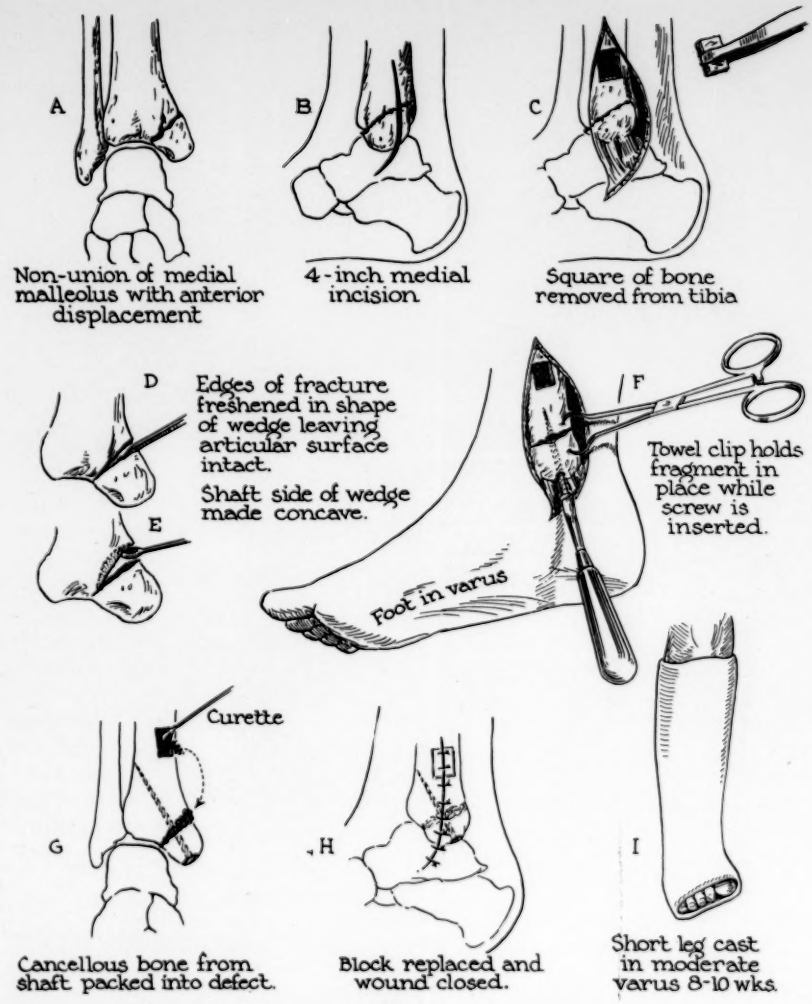

FIG. 1

Artist's drawing showing surgical technique for treatment of non-union following fracture of the medial malleolus. (Reproduced, by permission of The Year Book Publishers, Inc., from Compere and Banks' *Pictorial Handbook of Fracture Treatment*, Ed. 2. Chicago, 1947.)

CASE 2. J. R. C., a male, aged thirty-eight, slipped on uneven ground in September 1945, and sustained a bimalleolar fracture of the left ankle with lateral dislocation of the foot. Closed reduction was performed under general anaesthesia at an army hospital, and the ankle was immobilized in a leg cast for fourteen weeks. When the patient was discharged from the Military Service, he was told that the medial malleolus had not united, but he refused further treatment.

On July 2, 1947, the patient entered Hines Veterans Hospital, complaining of severe pain in the region of the left medial malleolus. He had been unable to work as a laborer because of the ankle disability. The physical examination showed swelling and tenderness over the posterior tibial tendon behind the malleolus; roentgenograms showed non-union of the medial malleolus (Figs. 3-A and 3-B).

On July 5, an open reduction and grafting with cancellous bone were carried out. Roentgenograms ten weeks later (Figs. 3-C and 3-D) showed union of the malleolus, and the cast was eliminated. The screw was subsequently removed, although it was not causing symptoms. The final result was excellent, and the patient is now working as a laborer.

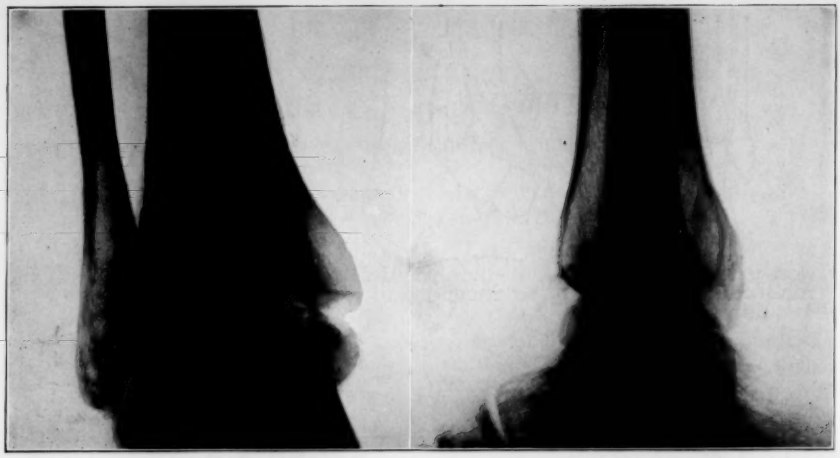

FIG. 2-A FIG. 2-B

Case 1. Anteroposterior and lateral roentgenograms of right ankle show non-union of the medial malleolus with persisting slight lateral displacement of the foot.

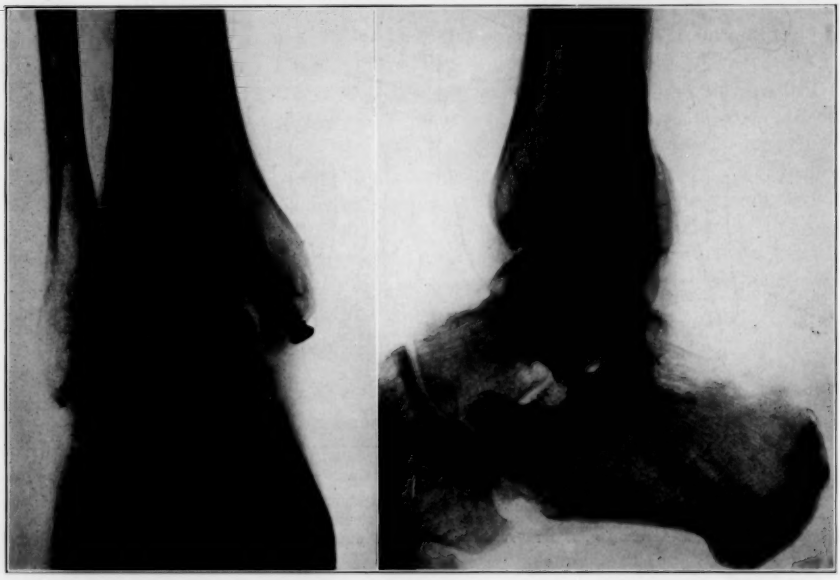

FIG. 2-C FIG. 2-D

Roentgenograms obtained eight weeks after operation show union of the medial malleolus. Note the correction of the space between the malleolus and the talus.

DISCUSSION

The treatment of non-union of the medial malleolus, as recommended by Campbell, Watson-Jones, and other authors, employs a full-thickness bone graft, taken from the proximal end of the same tibia through a second incision. The graft is either inlaid, so as to cross the fracture site; or is fashioned into the form of a peg and passed upward through the malleolus into the tibia, similar to a metal nail. Although one may expect a high percentage of union when either of these methods is utilized, the technique using

cancellous bone, as described in this paper, offers certain advantages, especially its simplicity of execution. Considerable operating time is consumed in fashioning a cortical-bone peg; it offers poor fixation; and, because of its small caliber, it frequently breaks as the graft is being inserted. At the same time, the total thickness of bone which crosses the site of non-union is small. The inlay type of bone graft is not appropriate for this condi-

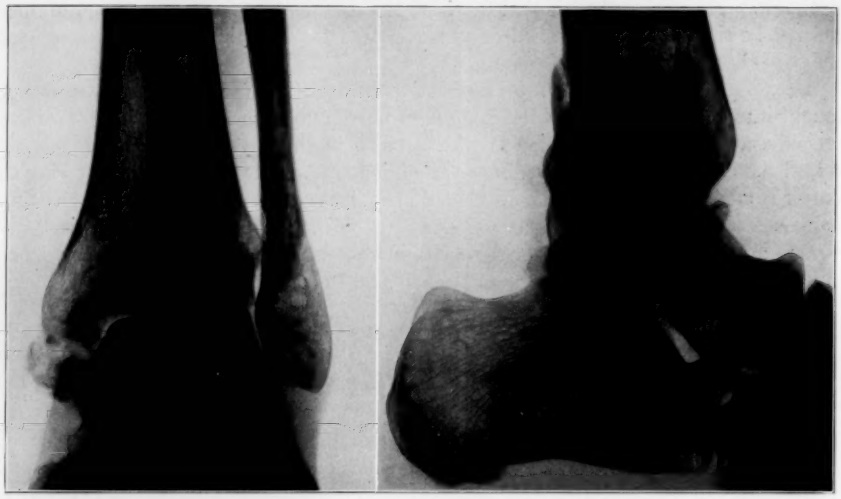

FIG. 3-A FIG. 3-B

Case 2. Non-union of the medial malleolus with anterior displacement, twenty-one months after acute fracture.

FIG. 3-C FIG. 3-D

Union of the malleolus was obtained ten weeks after bone-grafting, with return of painless function of the ankle joint.

tion, because of the small size of the malleolar fragment and the difficulty of maintaining fixation of the graft.

In contrast, the use of a metal screw results in strong internal fixation and permits early weight-bearing. Cancellous bone, which is packed into the triangular defect, will not only consolidate and be replaced more rapidly than a cortical graft, but the greater amount of bone transplanted to the site of non-union is more likely to stimulate union. Another important advantage is that the malleolar fragment, which is usually quite small, need not be significantly shortened or approximated to the tibia, except to restore continuity of the articular surface.

Occasionally, because of partial absorption of the malleolar fragment, it cannot be brought into contact with the tibia, in spite of maximum varus of the foot. In two such cases, the author fixed the malleolus with a screw in the best position obtainable and bridged the defect with cancellous bone. The bone must be prevented from entering the joint or coming into contact with the medial articular surface of the talus, for the resulting incongruous surfaces would cause an early arthritis.

The simplicity of the procedure saves considerable operating time, and union has been obtained within eight to ten weeks.

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ISOLATED FRACTURE OF THE CORACOID PROCESS *

BY MAJOR ROY C. ROUNDS, *Medical Corps, United States Army*

Because isolated simple fracture of the coracoid process is seen infrequently, the following case report is presented.

A housewife, who was five months' pregnant, slipped while carrying a two-year-old child and slid down a flight of twenty-two steps on her back. She arrived at the bottom of the stairs in a sitting position, with the child uninjured in her arms. Because of fear of an abortion, she reported to the Obstetric Clinic, in spite of the fact that she was suffering severe pain in the left shoulder and that movements of the left arm were painful.

When seen in the Orthopaedic Clinic, examination revealed ecchymosis and moderate swelling in the left mid-infraclavicular region; this region was extremely tender to pressure. She held the left arm acutely flexed at the elbow, and she supported it against her side with the right arm. Attempts to extend the forearm actively or passively produced severe pain in the region of the coracoid. All motions of the shoulder produced pain.

The only bone injury of the shoulder noted roentgenographically was a fracture through the base of the coracoid process, with complete separation of the coracoid from the scapula (Fig. 1).

Treatment consisted of immobilization of the acutely flexed arm against the chest with a muslin Velpeau dressing, reinforced with adhesive tape. After two weeks, the arm was transferred to a triangular sling, and careful active motion of the elbow and shoulder was encouraged. The sling was discarded two weeks later; at that time all pain had disappeared and roentgenograms showed union of fragments. Final roentgenograms taken two months after injury, when physical therapy had been discontinued, showed solid union of the fragments in anatomical position (Fig. 2).

* Published under the auspices of The Surgeon General, United States Army, who does not necessarily assume responsibility for the professional opinions expressed by the author.

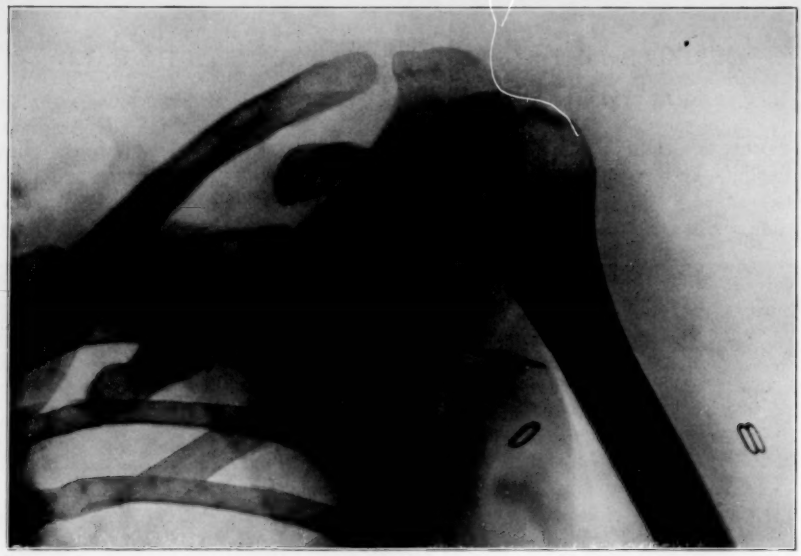

FIG. 1

Appearance of shoulder at time of admission.

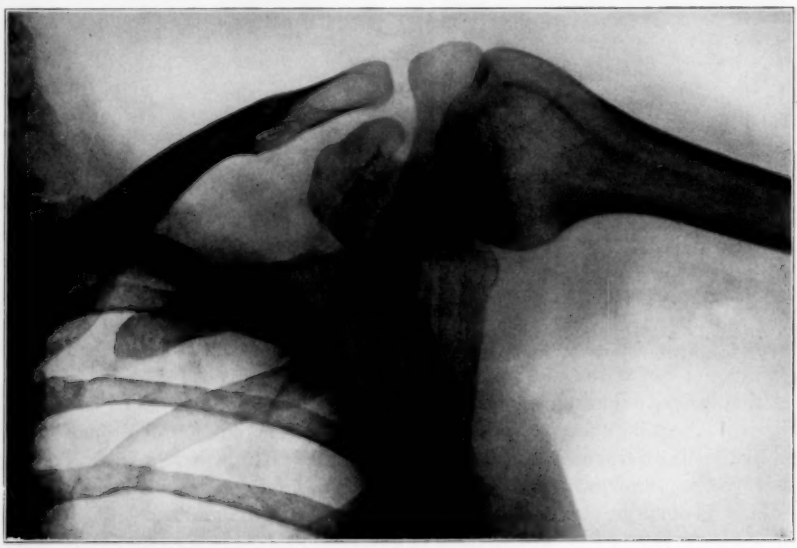

FIG. 2

Fragments had united solidly, two months after injury.

In this case, the fracture could not have been due to direct trauma, but was the result of indirect forces acting on the coracoid process. It was produced either by the force of sudden violent contraction of one or more of the three muscles attached to the process against a fixed scapula; or by sudden motion of the scapula away from these muscles, while they were in a contracted state.

SPRING SPLINT TO SUPINATE OR PRONATE THE HAND

BY STERLING BUNNELL, M.D., SAN FRANCISCO, CALIFORNIA

Spring or elastic splints coax joints into the position desired more efficiently than do rigid splints. In addition, they exercise the limb, improve its nutrition, and mobilize the joints.

At present the Funston splint is the most popular for holding the hand in supination.

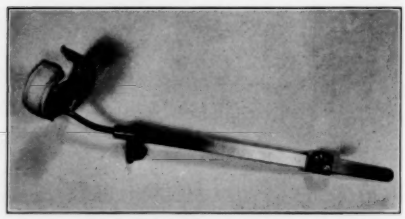

FIG. 1

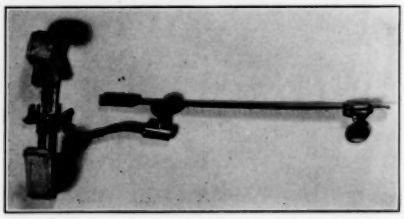

FIG. 2

Fig. 1: Special attachment which, when clamped to a standard right-angle elbow splint, will produce supination or pronation by a twist of the spring.
Fig. 2: Attachment dismantled to show cuff, axle and sleeve, torsion spring, and clamp.

FIG. 3

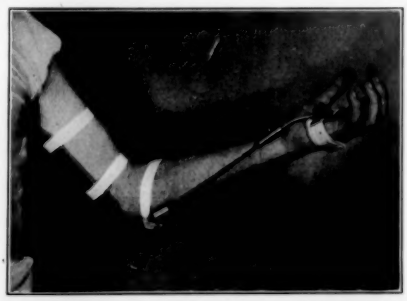

FIG. 4

Fig. 3: The hand is twisting the spring in the direction of pronation.
Fig. 4: The spring has rotated the hand into supination.

It consists of a right-angle iron along the medial side of the arm; cuffs are fastened to the arm, and a flat cuff at the end holds the hand.

A simple device that may be attached to a standard right-angle elbow splint is shown in Figure 1. A springy force of any desired amount, in supination or pronation, is produced by twisting a ribbon of spring steel (10 by 0.5 by .035 inches in size). The adjustment is by a set screw, which holds an axle in the desired position.

The strip of spring steel is fastened by a clamp at its proximal end to the medial edge of the upper portion of the forearm piece of a standard right-angle elbow splint. A padded flat cuff, adjustable to fit, encircles and controls the hand. A rod, curved to fit along the front of the dorsiflexed wrist, is fastened to the cuff by one central bolt in the palm. This short rod terminates proximally in a sleeve. A short axle, riveted to the end of the ribbon of spring steel, fits into this sleeve. The spring is twisted to give the desired degree of force in either supination or pronation (Figs. 3 and 4), and the axle on the spring is fixed in that position by a butterfly setscrew in the sleeve. The torsion force is transmitted to the hand by the flat cuff. The central bolt in the hand cuff allows the cuff to be turned so as to fit either hand.

FORCEPS FOR GRASPING AND HOLDING BONE PLATES

BY MEYER M. STONE, M.D., NEW YORK, N. Y.

The grasping and holding forceps presented here (Fig. 1) has proved helpful as a simple and secure method of handling a bone plate for fixation of a fracture. The forceps will facilitate the non-touch technique, and has many advantages for those who do not follow this technique. The operating field is unobstructed by hands holding the plate in

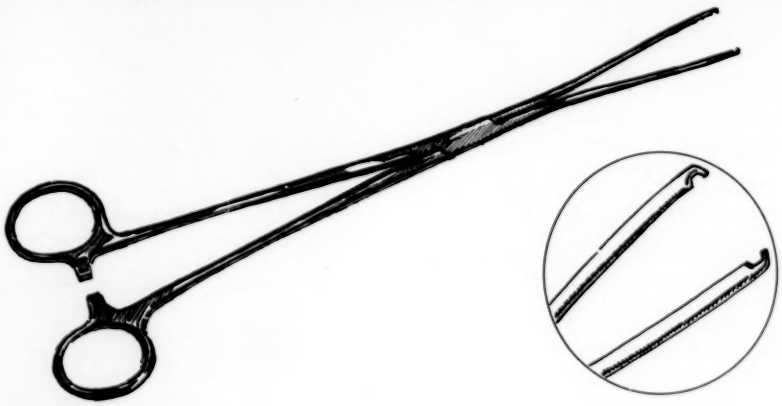

FIG. 1

Forceps, with detail of tip in circle.

the wound, and there is less danger of dropping the plate when held by the forceps than when it is held in the wet gloved hand or by the hemostat.

The forceps facilitates the handling of the bone plate and its application to the bone at the fracture site. The plate is held in place by an assistant, who is enabled to keep well out of the operator's field until the plate has been secured by one of several bone clamps, prior to insertion of the screws. When the plate is held firmly against the bone by the clamp, the forceps can be easily disengaged and removed by unlocking the ratchet.

Marring or scratching of the bone plate is reduced to a minimum, due to the design and construction of the instrument. It is recommended that the plate be grasped and held at the two end screw holes

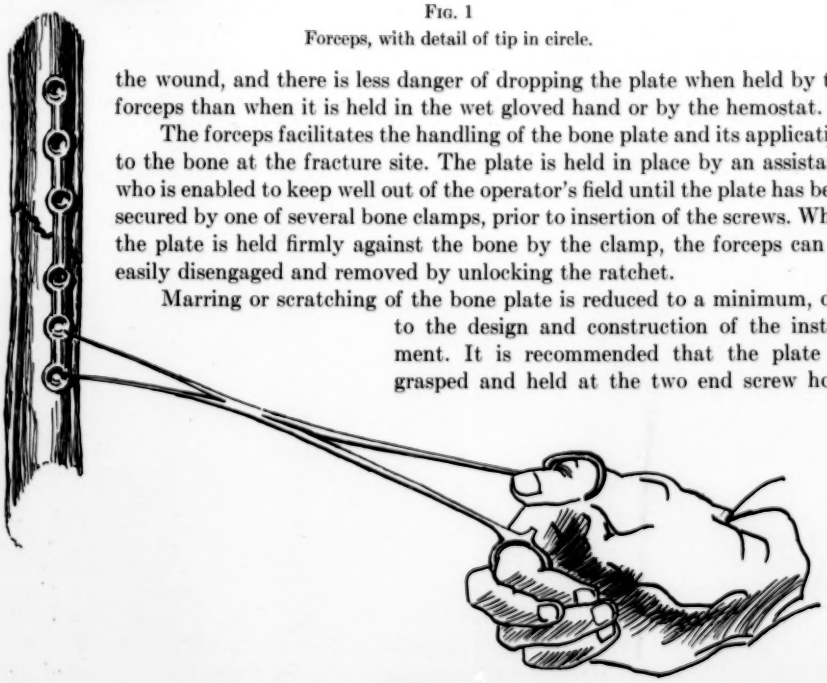

FIG. 2

Application of plate to bone surface with forceps, prior to clamping.

(Fig. 2), since the operator thereby has greater freedom in clamping the plate to the bone.

The forceps has been used by members of the surgical staff at the Beekman-Downtown Hospital, who have found it to be of considerable practical value.

LEGG-PERTHES DISEASE AND SLIPPED EPIPHYSIS IN THE SAME PATIENT

A Case Report

BY HERBERT R. MARKHEIM, M.D., BALTIMORE, MARYLAND

*From Kernan Hospital *, Baltimore*

In a review of a series of fifty cases of Legg-Perthes disease, one case was found in which Legg-Perthes disease developed in one hip while, at a later date, the other hip showed slipping of the capital epiphysis.

R. M., an eleven-year-old white boy, was admitted to Kernan Hospital on May 4, 1934, complaining of a limp on the left side. His mother stated that she had noticed the limp for about six months, but that there had been no complaint of pain. The past history and family history were non-contributory. The patient was well developed and well nourished. The spine was straight, but the left side of the pelvis was lower than the right. The child walked with a limp, favoring the left lower extremity. The left lower extremity was 1.2 centimeters shorter than the right. The left thigh measured 2 centimeters less than the right in circumference. The left hip lacked 15 degrees of flexion and 20 degrees of abduction when compared to the right hip. Internal and external rotation of the left hip were also restricted.

The urine showed a trace of albumin, but microscopic examination was negative. The red-blood-cell count was 4,500,000; the white-blood-cell count was 7,000; the hemoglobin was 75 per cent. The serological findings were doubtfully positive on two occasions, and negative the third time. Roentgenograms revealed bony destruction of the head and neck of the left femur, with flattening of the head (Fig. 1). A diagnosis of Legg-Perthes disease of the left hip was made.

Skin traction was applied to the left lower extremity for thirty days. Following this period, he remained in bed for ten days while an ischial caliper for walking was being made for the left lower extremity. The sole of the right shoe was built up about two inches, and the patient was permitted to walk. He was dis-

FIG. 1

R. M. Anteroposterior roentgenogram of both hips. Legg-Perthes disease is evident on the left.

* Service of Allen F. Voshell, M.D.

charged after two months of hospitalization. The patient was followed in the Clinic, and his brace was discarded after he had worn it for one and one-half years.

In December 1936, the child was again brought to the Clinic by his mother, who had observed that he

FIG. 2

FIG. 3

Anteroposterior and lateral roentgenograms of both hips, taken two years and eight months later, show Legg-Perthes disease of the left hip and slipped epiphysis of the right hip.

was "knock-kneed". On January 2, 1937, he was readmitted to the Hospital. The boy had been well until three months before admission, when an infection of the upper respiratory tract had developed, and a cough which persisted. Although he had not been weighed, his mother thought that he had lost some weight and that he "wasn't walking right".

Physical examination showed a somewhat undernourished, pale, blond boy, who was lying in bed in no apparent pain or discomfort. A marked apical thrust was palpated, 7 centimeters to the left of the mid-line at the fourth interspace. There was no thrill or arrhythmia. Following exercise, the pulse rate greatly increased and did not return to normal for some time. At orthopaedic examination, bilateral genu valgum was observed. The patient walked as though both hips were stiff. There was an increase in lumbar lordosis, and both greater trochanters seemed slightly elevated. The left thigh was 1 centimeter smaller than the right in circumference. The right lower extremity was 1.2 centimeters shorter than the left. Motion at the hips was as follows: flexion, 120 degrees on each side; abduction, 15 degrees on each side; adduction, normal on each side; external rotation—left 5 degrees, right 5 to 10 degrees; internal rotation, 0 degrees on each side; extension—left 0 to 5 degrees, right 5 to 10 degrees.

At the time of admission the urine contained albumin (+++), leukocytes, and hyaline casts; weekly determinations for twenty-two weeks demonstrated no change. The red-blood-cell count was 3,250,000; the hemoglobin was 65 per cent.; the white-blood-cell count was 7,400. Serological findings were negative. The non-protein nitrogen at the time of admission was 146 milligrams and the creatinine was 4.3 milligrams per 100 cubic centimeters.

Roentgenograms of the left hip showed nearly complete destruction of the head of the femur, shortening of the neck, increase of the joint space, and coxa vara. The right hip demonstrated a slipped epiphysis, widening of the neck of the femur, and destructive changes at the epiphyseal plate (Figs. 2 and 3). The diagnoses were Legg-Perthes disease of the left hip, slipped epiphysis of the right hip, and chronic glomerulonephritis.

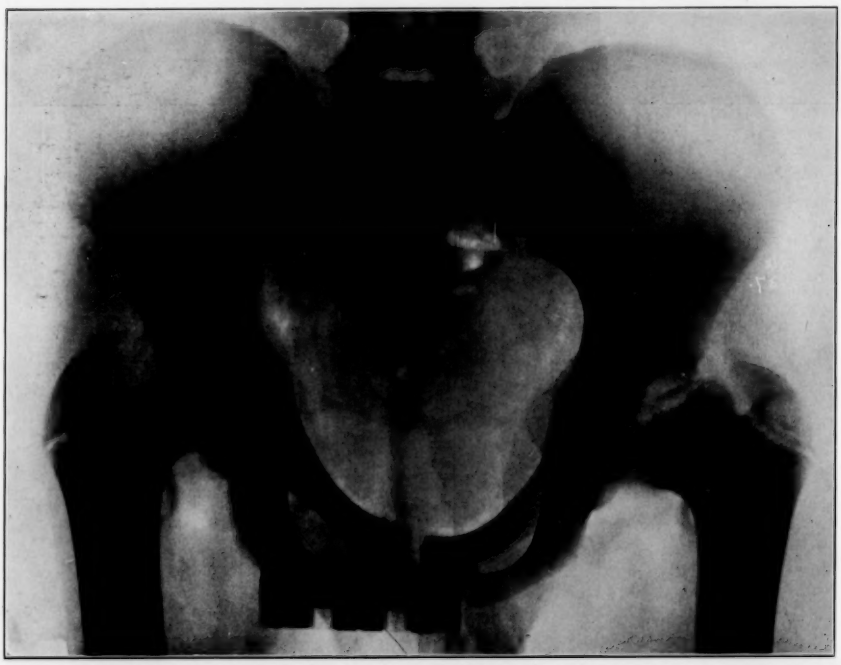

FIG. 4

Roentgenogram taken three years after Fig. 1.

While the boy was in the Hospital, both lower extremities were placed in skin traction for two months. After removal of the traction, the limb lengths were equal. Abduction and internal rotation were markedly restricted bilaterally, yet the patient seemed to be able to walk much better. He was afebrile during his four and one-half months in the Hospital, and the non-protein nitrogen dropped to 82 milligrams per 100 cubic centimeters. He was discharged on June 22, 1937 (Fig. 4).

FRACTURES OF THE ANKYLOSED SPINE

BY ERNST W. BERGMANN, M.D., NEW YORK, N. Y.

From the Orthopaedic Service of Bellevue Hospital, New York City*

Fractures of the vertebral column in Marie-Strümpell disease are uncommon, yet in recent years a number of such cases have been seen by members of this Staff, some on this Service and some elsewhere.

Very little has appeared on this subject in the literature; all the author has been able to find are two single case reports from the German literature,—one by Abdi[1], in 1903, and the other, by Stiasny[2], in 1933. The first referred to a fracture of the lumbar spine in which the cauda equina was crushed, and the next to a fracture between the fifth and sixth cervical vertebrae, remarkable by the absence of gross neurological changes and also by its speedy consolidation.

To these we can add four cases of fracture through the lower cervical segments. A fifth case of this type is not included, as the patient died shortly after he was admitted to this Hospital. Although no definite conclusions can be drawn from this small number, the cases have much in common. They all occurred in middle-aged men with a long history of ankylosis of the spine, complete from the occiput to the pelvis. This completeness of bony fusion over the entire spine appears to be a pertinent factor in the fracture mechanism, as

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. A recent fracture through the interspace between the fifth and sixth cervical vertebrae.

Fig. 1-B: The fracture has consolidated.

the absence of any spring action within the spine makes it impossible for the impact of a fall to be absorbed.

Unlike a fracture of the compression type in the ordinary spine, the ankylosed spine breaks like a long bone, transversely, as a result of a bending force. All the fractures oc-

* Arthur Krida, M.D., Director.

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 2. A recent fracture, at the same level as in Case 1.
Fig. 2-B: After healing of the fracture.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 3. A recent fracture, at the same level as in Cases 1 and 2.
Fig. 3-B: After healing of the fracture.

curred through what had formerly been the interspace, rather than through the substance of the body itself. Most of them were at the level of the interspace between the fifth and sixth cervical vertebrae. The time necessary for bony consolidation was uniformly short, the underlying tendency toward ankylosis obviously being responsible. The amount of cord or root involvement was in no way related to the degree of anatomical displacement seen in the roentgenogram. However, the roentgenograms taken in the hospital do not necessarily represent the situation which existed at the moment of injury.

Although such a fracture is a serious injury, it may afford an opportunity to attempt a certain degree of correction of the flexed attitude of the head, in order to improve the range of vision. Conservative treatment in the form of head traction in a Sayre halter for

several weeks, followed by the wearing of a plaster collar, has proved adequate. The amount of traction, and particularly the direction in which it is exerted, has to be applied with great care for the individual patient.

CASE 1. The fracture occurred when the patient was struck by a taxicab. The exact mechanism of his fall could not be established, as he was intoxicated and confused at the time of admission. From the displacement which was present (Fig. 1-A), it would appear that he landed on his back and that his head, following the momentum, snapped backward. Despite the pronounced anatomical separation with wide anterior opening of the fifth interspace, neurological symptoms remained negligible.

After three weeks in a Sayre halter, the neck was sufficiently stable to permit the application of a plaster collar. This was taken off six weeks later, at which time the roentgenogram revealed firm bony consolidation (Fig. 1-B). It also showed the head in a slightly more extended position than prior to the injury, a fact which was borne out by the patient's statement that his range of vision had increased.

CASE 2 (Observed by Dr. Krida). This man fractured his spine by slipping in the bath tub and hitting his head on the tub. As a result, the upper fragment was in a slightly more flexed attitude (Fig. 2-A) than before the injury. Here, again, symptoms referable to the nervous system remained insignificant. The roentgenogram of the healed fracture (Fig. 2-B) showed the neck definitely more extended, with consequent improvement of the range of vision.

CASE 3 (Observed by Dr. E. Blumenfeld). In this case the patient, while intoxicated, fell and struck the shoulder region against the ground, his head snapping backward. The first roentgenogram (Fig. 3-A) showed perhaps the slightest degree of displacement, yet he had immediate loss of power in all four extremities. Any change in position of the head would lead to cessation of respiration; only when the head was placed in its original degree of flexion was respiration resumed. Complete recovery from neurological symptoms, as well as bony union, occurred within six weeks (Fig. 3-B). The position of the head and the range of vision remained unimproved.

FIG. 4

Case 4. Healed fracture through the interspace between the sixth and seventh cervical vertebrae.

CASE 4. This man fractured his neck by falling down a flight of stairs, the head being pushed toward the chest. He did not enter the Hospital until about one month later, so that no roentgenogram was taken immediately after the injury. He was placed in a Sayre halter with the result that an existing paraesthesia of three fingers of the left hand promptly disappeared. The roentgenographic picture after seven weeks (Fig. 4) showed a healed fracture through the sixth interspace. The patient stated that his neck was not quite so flexed as before, and that he could look straight ahead with less effort.

In three of the four cases, some correction of the flexed attitude of the head was obtained, with corresponding improvement of vision. The healing of the fracture itself was extraordinary, almost rapid. In each case the neurological symptoms cleared up entirely or became insignificant.

1. ABDI, O. H.: Ueber einen Fall von chronischer Arthritis ankylopoetica der Wirbelsäule. Fractur der Wirbelsäule und Quetschung der Cauda equina. Mitt. a. d. Hamburgischen Staatskrankenanstalten, **4**: 57–75, 1904.
2. STIASNY, H.: Fractur der Halswirbelsäule bei Spondylarthritis ankylopoetica (Bechterew). Zentralbl. f. Chir., **60**: 998–1001, 1933.

TRIGGER THUMB IN INFANTS

BY EDWIN E. SPRECHER, M.D., SEATTLE, WASHINGTON

Few cases of trigger thumb are reported in the American literature. As a result, many physicians are not familiar with the condition and it is often misdiagnosed. In 1936, Jahss reported ten cases, in all of which operation was carried out. He believed that the only treatment for this lesion is surgical. In 1940, Beck reported six cases. In his opinion, this is a degenerative lesion which can be cured by splinting. Zadek, in 1942, reported two cases, both of which were cured by operation. He believed that the lesion is congenital. Rose, in 1946, reported two cases in which the disability was bilateral. He stated that the etiological factor is similar to that of de Quervain's disease, and that in these cases an audible snap may be produced.

Twelve cases with adequate follow-up examinations, which form the basis of this report, have been selected from a series treated at the Orthopaedic Hospital in Los Angeles.

The usual history of trigger thumb in infants is that the mother has noticed that the thumb cannot be completely extended. It may be extended easily to about 150 degrees; further effort causes the thumb to jerk before extension is complete. The thumb can be flexed about 30 degrees; it will then jerk before flexion can be continued freely during the rest of the excursion. After these symptoms have been present for several months, the thumb locks and can no longer be extended beyond 150 degrees. Active and passive motion throughout the rest of the arc of motion remain free. Often the "locking" or inability to extend the thumb completely is the first recognized symptom. Although some writers state that there is an audible snap, we have not observed this sign and have had no patients who included this in the history.

There is no history of trauma, and the child apparently has no pain. In all of these patients, symptoms appeared before the age of three years; and in four patients, locking of the thumb was noticed immediately after birth.

PHYSICAL EXAMINATION

Examination reveals a small, non-tender, palpable mass on the flexor surface of the thumb, over the neck of the metacarpal. As the thumb is moved, the mass moves up and down with the flexor tendon. The snapping is the only other abnormal finding. In three of the cases, the condition was bilateral; in two other cases, nodules were palpable in the opposite thumb, although there were no symptoms on this side. In five patients the symptoms were in the right thumb; in four, in the left. In three patients the first symptom noted was snapping of the thumb. In the remaining nine, the first symptom was that the thumb had locked in flexion.

MECHANISM OF INJURY

The tendon of the flexor pollicis longus is found to have a diffuse enlargement and the tendon sheath a constricted area at the level of the metacarpal head. The thumb can be extended until the enlarged portion of the tendon comes in contact with the constricted portion of the sheath. Further extension causes a jerking, as the enlarged area of the tendon slips through the constricted sheath. In certain stages of the ailment, the mass can be made to slip through the constricted area passively when the force required is so great that it cannot be done actively. When locking occurs, the nodule is always on the proximal side of the constricted area. The flexor muscles are stronger than the extensors and can pull the nodule through when the extensors are no longer able to do so. Since the nodule is on the tendon of the flexor pollicis longus which is attached to the distal phalanx, only the distal joint is involved in the process. Neither flexion nor extension is disturbed at the metacarpophalangeal joint.

FIG. 1

Photomicrograph of a section of tissue taken from the nodule in the tendon.

ETIOLOGY

Since de Quervain's original report in 1895, numerous articles have been written on stenosing tenosynovitis, either at the radial styloid or involving the flexor tendons of the fingers. It is agreed that the etiology in these cases is trauma. Because the findings in snapping thumb in infants are the same, it is logical to conclude that the etiological factor is the same.

It has been suggested that, because the condition is sometimes present at birth, it is of hereditary origin. There is nothing in the development of the embryo which renders this area susceptible to the development of an abnormality. Sections of the tendon show evidence of trauma. A great number of lymphocytes and monocytes are present in the stroma of the tendon. There is no evidence of bacterial invasion, and the large number of cells suggests a traumatic process rather than a hereditary one. Anyone who has observed an infant has noticed that much of the time the fingers are closed over the thumb, keeping it in sharp flexion. The tendon sheath has a normal thickening and constriction in this area, which act as a pulley. It is conceivable that keeping the tendon sharply kinked over the pulley produces sufficient trauma to cause the lesion. Since infants hold the hand in this position immediately following birth, it is possible that they do so before birth, also; if so, a traumatic process may be established by the time the infant is born. It might be argued that this apparently minor trauma would not cause such a lesion, but in many cases of trigger finger in adults no specific trauma can be cited. The cause must be ascribed to the

trauma under the heading of "wear and tear". Certainly this is no more severe than a continual kinking over the pulley.

PATHOLOGICAL FINDINGS

The pathological findings are similar to those found in trigger finger in adults: The pulley is thickened and constricted. There is no excess fluid in the sheath, and the tendon slides freely in the sheath. There are no adhesions between the tendon and the sheath, and no evidence of infection is present. The tendon has a fusiform enlargement which has the appearance of normal tendon tissue. When an incision is made into the enlargement, the tissue cannot be distinguished grossly from the adjacent tendon. In the literature, only one instance was found where a biopsy had been taken of the nodule. A microscopic section of the nodule taken from Case 11 in this series shows normal tendon tissue, infiltrated with lymphocytes and monocytes. The general appearance is consistent with traumatic inflammation.

TREATMENT

Some of these patients had an initial period of conservative treatment, but this proved unsatisfactory and surgery was resorted to in all cases. The ages at the time of operation ranged from eight months to six years; the average age was twenty-nine months. The oldest patient was thirty-four months at the time symptoms were first noted; in four patients the symptoms were noted at birth. The average age was twelve and one-half months.

Treatment for this condition is incision of the pulley. Although some authors state that immobilization of the thumb will give satisfactory results, we cannot agree. Even in one case in which the symptoms disappeared, the original condition returned soon after removal of the splint. When one is not familiar with the lesion, the usual procedure is to expose the distal joint, but this is not desirable.

In all cases the sheath was incised. In two cases a portion of the nodule was removed, as advocated by some authors, and in the remaining ten the nodule was left intact. We do not recommend removal of the nodule, since in no case in which the sheath alone was split was there a return of symptoms.

Method: A small transverse incision is made, one-eighth of an inch distal to the proximal flexion crease of the thumb. The incision is placed distally, because there is no subcutaneous tissue in the crease itself and the scar would, therefore, become more adherent. The incision is placed on the volar and lateral surfaces of the thumb to avoid the sensory nerve to the lateral aspect, since at this level the sensory nerve is almost directly over the flexor surface. The sheath is split near the base on one side. If it is split in the center, scar tissue will be produced at the point of maximum friction. The wound is closed by suturing the skin only. No immobilization is necessary.

RESULTS

The longest follow-up period was seven and one-half years; the shortest was six months. The average follow-up for the twelve cases was twenty-six months. Good results were obtained in all of the patients, and there were no complications. In no case was there any lack of motion or strength, or any symptoms of discomfort.

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ANDRY AND THE *ORTHOPAEDIA* *

BY R. BEVERLY RANEY, M.D., DURHAM, NORTH CAROLINA

I want you to picture an old man writing a book. He is eighty-three. The place is Paris, where he is Professor of Medicine in the Royal College and former Dean of the Faculty of Physick. The time is 1741,—fifty years before the French Revolution and a century before the discovery of ether anaesthesia. Our author's face, we can imagine, shows the scars of time and many a bitter professional battle. His eyes, however, are still bright with originality as he writes an opening paragraph and creates a new tool of thought (Fig. 1): "As to the Title, I have formed it of two Greek Words, viz. *Orthos*, which signifies streight, free from Deformity, and *Paidion*, a Child. Out of these two Words I have compounded that of *Orthopaedia*, to express in one Term the Design I propose, which is to teach the different Methods of preventing and correcting the Deformities of Children" [3].

I.

Explication du titre d'Orthopédie. Quant au titre en queſtion, je l'ai formé de deux mots grecs, ſçavoir, d'*Orthos* qui veut dire *droit, exempt de difformité, qui eſt ſelon la rectitude*, & de *Paidion*, qui ſignifie *Enfant*. J'ai compoſé de ces deux mots, celui d'*Orthopédie*, pour exprimer en un ſeul terme, le deſſein que je me propoſe, qui eſt d'enſeigner divers moyens de prévenir & de corriger dans les enfans, les difformités du corps. L'expreſſion m'a paru d'autant plus permiſe, que les deux célébres Auteurs que je viens de citer, en ont employé de ſemblables; le premier en donnant le titre de *Pédotrophie* à un Traité ſur la *maniere de nourrir les Enfans à la mammelle*; & le ſecond, celui de *Callipedie* à un Traité ſur les *moyens d'avoir de beaux Enfans*. Deux titres qui ſont tirés tout de même, du grec; le premier de *Pais* Enfant, & de *Trophe* nourriture; & le ſecond de *Kalos* Beau, & de *Paidion* Enfant.

I.

As to the Title, I have formed it of two Greek Words, *viz.* Ὀρθὸς, which ſignifies ſtreight, free from Deformity, and Παιδίον, a Child. Out of theſe two Words I have compounded that of *Orthopædia*, to expreſs in one Term the Deſign I propoſe, which is to teach the different Methods of preventing and correcting the Deformities of Children. The Expreſſion ſeemed to me the more allowable, that the two celebrated Authors above cited, have made uſe of Terms of the ſame Kind; the firſt in giving the Title of *Pædotrophia* to a Treatiſe upon the Manner of ſuckling Infants; and the ſecond that of *Callipædia*, to a Poem upon the Method of getting beautiful Children: both which Titles are likewiſe taken from the Greek; the firſt from Παῖς an Infant, and Τροφὴ Nouriſhment; and the ſecond from Καλὸς beautiful, and Παιδίον a Child.

Explication of the Title of Orthopædia.

FIG. 1

Andry's creation of the term *Orthopédie*.

The word "orthopaedics," like its creator, has had adversaries and has outlived them. "Orthosomatics", "orthontropia", the "orthomorphia" of Delpech and the "orthopraxy" of Heather Bigg are now strange even to medical ears. To the term "orthopaedics" has come gradually increasing acceptance, tempered always with a realization that the subject has far outgrown the literal meaning of its title. A century after Andry, Valentine Mott

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 26, 1949.

L'ORTHOPEDIE
OU
L'ART
DE PREVENIR ET DE CORRIGER
DANS LES ENFANS,
LES DIFFORMITÉS DU CORPS.

LE TOUT PAR DES MOYENS A LA PORTE'E des Peres & des Meres, & de toutes les Perſonnes qui ont des Enfans à élever.

PAR M. ANDRY, CONSEILLER DU ROY, Lecteur & Profeſſeur en Médecine au College Royal, Docteur-Regent, & ancien Doyen de la Faculté de Médecine de Paris, &c.

Avec Figures.

TOME PREMIER.

A PARIS, RUE SAINT JACQUES.

Chez { La Veuve ALIX, au-deſſus de la ruë des Noyers, au Griffon. / LAMBERT & DURAND, à la Sageſſe, & à Saint Landry.

M. DCC. XLI.

AVEC APPROBATIONS ET PRIVILEGE DU ROI.

ORTHOPÆDIA:
Or, the ART of
CORRECTING and PREVENTING
DEFORMITIES
IN
CHILDREN:

By ſuch MEANS, as may eaſily be put in Practice by PARENTS themſelves, and all ſuch as are employed in Educating CHILDREN.

To which is added,
A DEFENCE of the ORTHOPÆDIA, by way of SUPPLEMENT, by the AUTHOR.

Tranſlated from
The *French* of M. *ANDRY*,
Profeſſor of Medicine in the ROYAL COLLEGE, and Senior Dean of the Faculty of PHYSICK at *Paris*.

IN TWO VOLUMES.

Illuſtrated with CUTS.

VOL. I.

LONDON:
Printed for A. MILLAR, at *Buchanan's Head*, oppoſite to *Catharine-ſtreet*, in the *Strand*.

M. DCC. XLIII.

FIG. 2
Title pages of French and English editions of the *Orthopaedia*.

referred to "that beautiful and exact science *limitedly* denominated Orthopoedic Surgery". Two centuries after Andry, Royal Whitman wrote: "The ancient, ambiguous but irreplaceable term 'orthopaedic', which for those who accepted its restrictions was an insuperable obstacle to progress, is now generally understood as indicating only a sphere of action". The meaning and the influence of orthopaedic surgery must continue to grow. It is up to us to see that its standards remain high and that its further development, like that of Andry's children, is straight and healthy.

The original, Paris edition of the *Orthopaedia* [2] was published in two duodecimo volumes in 1741. Its title page (Fig. 2) includes a reference to the sanction of the king. The English edition [3] is an anonymous translation which was published in London in 1743. A Belgian edition appeared in 1742, and German editions in 1744 and 1762. The English volumes include, as mentioned on the title page, a translation of Andry's *Suite d'Orthopédie*, a spirited rebuttal of criticisms leveled at the *Orthopaedia*. Both Paris and London editions include Andry's thesis on the virtues of exercise (Fig. 3), which is entitled: "Whether moderate Exercise is not the best Preserver of Health?"

Both French and English editions are illustrated by fifteen pages of copper-plate engravings. An example (Fig. 4) contrasts proper and faulty sitting posture in reading. The frontispiece (Fig. 5) is an allegorical drawing of children, mother, and orthopaedic doctrine. Most celebrated of the illustrations, however, is that of the splinted tree (Fig. 6), which has gained wide recognition as a symbol of orthopaedic endeavor.

The text of the *Orthopaedia*, divided into four books (Fig. 7), describes the parts of the body, classifies the deformities of children, analyzes causes, and presents methods of prevention and treatment. Andry writes in a natural, wholesome, vivid style. Sample subtitles are: "The Body like the Back of a Spoon" and "The Method of preventing

QUÆSTIO MEDICA,

Cardinalitiis Diſputationibus manè diſcuſſa, in Scholis Medicorum, die 4 Martii 1723, *&* 23 Martii 1741. *Præſide M.* NICOLAO ANDRY, *Doctore Medico, Lectore ac Profeſſore Regio, nec non Librorum Cenſore.*

An præcipua Valetudinis tutela Exercitatio?

IN iis omnibus quæ ad bonam integramque corporis conſtitutionem tuendam, plurimoſque ejuſdem languoris præcavendos ac propulſandos conferre maximè valent, primum ſibi locum vendicat exercitatio. Eſt enim hæc caloris innati ſuſcitatrix, exuperantium humorum caſtigatrix, corruptorum emendatrix, agilitatis ac promptitudinis artuum parens legitima, nervis ac juncturis roborandis idoneum auxilium, nec non præſtantiſſima apertionis pororum ac meatuum cauſa: unde fit ut ſingulæ corporis partes firmentur, inſtaurenturæ

Joſ. Quercetani Diatetic. Polyhiſtor.

A

THESIS

Defended before the COLLEGE of PHYSICIANS in *Paris*, the fourth Day of *March*, 1723. and the twenty-third of *March*, 1741. Dr. ANDRY, Reader, Profeſſor, and Cenſor Royal of the ſame Faculty, being at that time Preſident, *viz.*

Whether moderate Exerciſe is not the beſt Preſerver of Health?

I.

OF all the Methods proper for preſerving Health, and for preventing, and even curing a great number of Diſeaſes, there is none equal to moderate Exerciſe. It at the ſame time rouſes the natural Heat, diſſipates the ſuperfluous Humours, corrects thoſe that are acrid, gives Agility to the Muſcles, ſtrengthens the Nerves and Joints, opens the Pores, and aſſiſts the Perſpiration. Hence the whole

FIG. 3

Title page of Andry's thesis on the value of exercise (English edition).

Children from pushing out the Backside too much". The fourth book (Fig. 8), which deals with deformities of the head and even disorders of the complexion and defects of the voice, has been criticized widely as having nothing to do with orthopaedics. Andry, however, doubtless interpreted deformity as including disfigurement. It must be remembered that Andry was not writing primarily a scientific treatise, but a guide for the raising of healthy children. As Kirmsse has pointed out, the pioneer of a new subject is likely to give either too little or too much.

A more valid indictment of the *Orthopaedia* is that many of the treatments which it advocates are extremely weak or quite valueless[4]. We should expect little correction of deformity from the active exercise occasioned by awakening the patient each morning with cold water thrown in his face, nor can we second Andry's treatment of applying to sprains "a well roasted salt Herring".

Despite such defects, the *Orthopaedia* contains an astonishing store of pertinent information and deserves fully the approval which it has received. It collects and correlates the various deformities of the external parts of the body. It directs attention to the supervision demanded by the physical needs of children, demonstrates the harmful effects of improper body mechanics at rest and in motion, and specifies a preventive as well as a corrective therapy. The basic importance of clinical observation of the patient is brought out; the superiority of early treatment to late is repeatedly stressed. Andry calls attention to the value of gentle massage and to the need for repetition and patience in the use of corrective manipulations. The importance of simple gymnastics, of exercising deficient muscles, and of prescribing active exercise rather than passive movement is clearly set forth. Andry describes and recommends what we now refer to as muscle-setting exercises. He considers psychological aspects of treatment and prescribes recreational therapy. In one paragraph he deprecates the use of soft beds and pillows; in another he recommends raising one border of the shoes if "the Feet incline too much to one Side". In some instances overcorrection of deformity is advised. For acute minor injuries the value of immediate immersion in cold water is mentioned. There is even a reference to

FIG. 4

Andry's illustrations of a proper and an improper sitting posture (English edition).

FIG. 5

Frontispiece of the *Orthopaedia* (English edition).

FIG. 6

Andry's splinted tree, used in the *Orthopaedia* to illustrate the treatment of bowing of the leg

ORTHOPÆDIA.

BOOK FIRST.

A general Deſcription of the external Parts of the Body.

THE human Body is divided into the Trunk and Extremities. The Trunk is ſupported by the Spine or Back-Bone, and comprehends three Cavities; *viz.* 1. The Head, which Anatomiſts call the upper Cavity, and is ſupported by the Neck; 2. The Thorax or Cheſt, called by Anatomiſts the middle Cavity; 3. The Belly, properly ſo called, to which they give the Name of the lower Cavity.

THE Extremities are the Arms and Legs. I ſhall only deſcribe theſe Parts as to their external Appearance. Each of them is divided into a great many others, ſome of which have Names known by every body, while the Names of others are not ſo common. I ſhall name and deſcribe

BOOK SECOND.

The Means of preventing and correcting the Deformities of the Body in Children; and firſt, a Deſcription of the Body.

BY the Body is underſtood the Trunk of the Body; which comprehends, 1. The Head; (but the Head, properly ſo called, and conſidered only with reſpect to its Figure, independant of the Face;) 2. The Spine; 3. The Cheſt; 4. The Loins; 5. The lower Belly and the Back-ſide.

Of the SPINE.

THE Spine is that long Chain of moveable Bones, placed one upon another, all along the Back, from the top of the Neck down to the Rump, and compoſes that flexible Column upon which the Head is placed, as on an Axis, with reſpect to the firſt Vertebræ.

WHEN the Spine is ſtrait, well ſet, and finely turned, it makes a handſome Body; and when it is crooked and ill turned, the Body is deformed.

THE upper part of the Cheſt is attached to the Spine above, and the Haunches below;

FIG. 7

Title pages of first and second books of the *Orthopaedia*.

the ready healing of "porous and spongy" bone. The modern ring of many of these concepts is immediately apparent.

Andry's death one year after the publication of the *Orthopaedia* brought to a close an active life, filled with personal and professional strife. Nicolas Andry was born, the son of a poor merchant of Lyons, in 1658. He studied for the clergy, tutored to help meet expenses, and later became a professor of theology [8, 13]. His restless nature was unsuited, however, for the quiet life of the church; at the age of thirty-two he abandoned theology and undertook the study of medicine. He graduated at Reims in 1693, and was admitted to the Faculty of Medicine at Paris in 1697. He became a prolific writer of medical papers, discussing varied subjects including diseases of bone, diet, bleeding, purgation, and abstinence from liquor. Andry is said to have written the first description of infra-orbital neuralgia.[12] His book on worms[1], advancing the theory that each part of the body has its respective pathogenic worms, brought wide recognition; it also brought him considerable opposition and the nicknames *homo vermiculosus* and *homo verminosus*. Andry was sharply criticized for conniving with the apothecaries to sell his proprietary vermifuge. In addition to medical contributions, Andry wrote innumerable polemics and invectives. His criticisms of another author might well be applied to his own papers: "An ungoverned Heat prevails . . . it is not possible for more Passion to be discovered in writing"[3].

In 1712 Andry became Professor of Medicine at the College of France in Paris; twelve years later he was made Dean of the Faculty of Medicine. This office he filled for two memorable years in which his prodigious activity and turbulent spirit were fully displayed. Already he had had many contests with the surgeons, of whom Jean-Louis Petit, author of a famous treatise on injuries and diseases of bone, is perhaps the best known. On becoming Dean, Andry did everything in his power to see that the surgeons were shorn of their privileges and that the rights of the Faculty of Medicine were aug-

BOOK THIRD.

Deformities of the Arms, Hands, Legs and Feet.

1. *The* ARMS *too ſhort or too long.*
2. *The* LEGS *too ſhort or too long.*

WE ſee ſome Perſons who have both the Arms too ſhort, or too long; and ſome that have one ſhorter or longer than the other. We ſee them alſo with other Deformities of thoſe Parts, as Knots, Crookedneſs, Diſtortions, *&c.* The ſame is obſerved of the Hands, Legs and Feet. When they are born with thoſe Defects, there is no Cure to be attempted, unleſs they are occaſioned by ſome Violence which the Infant ſuffers from the Midwife.

A FAMOUS King of *Perſia* * had his right Hand longer than the left, and it was ſo long that he was ſurnamed *Longamanus*. *Darius* and *Alexander*, as ſome Hiſtorians report, had their Arms ſo long, that they reached down to their Knees. We oft enough ſee People who have their Arms ſo ſhort, that they are obliged when they eat or drink, to bow down their Head to their Hands.

As

* *Artaxerxes* the firſt, called *Artaxerxes Longamanus*.

ORTHOPÆDIA.

BOOK FOURTH.

The Deformities of the HEAD.

The Means of preventing and correcting thoſe Deformities.

THE Head, to repeat here what we ſaid in the Beginning of the firſt Book, includes the Skull, the Hair, and the Face. The Skull is the Caſe of the Brain, the Hair is the Covering of this Caſe, and the Face is a Compoſition of thoſe Parts which compoſe the whole Fore-part of the Head. Thus we have three Sorts of Deformities to ſpeak of here: Firſt, thoſe which affect the Head, with reſpect to the *Cranium*; ſecondly, thoſe with reſpect to the Hair; thirdly, thoſe with reſpect to the Face.

VOL. II. B *The*

FIG. 8

Title pages of third and fourth books of the *Orthopaedia*.

mented. Chéreau [8] states that no other physician fought with such blind fury to prevent the surgeons from obtaining the honorable rank to which the nature of their profession entitled them. Andry succeeded in obstructing the teaching of surgery by surgeons. He managed to have passed a rule forbidding lithotomy unless a physician were present, and another prohibiting the publication of any medical work without the approval of the Faculty of Medicine. Having disposed temporarily of the surgeons, Andry next engaged other members of the Faculty of Medicine in a struggle for power. As his intrigues became known, his popularity dwindled; and in 1726 he lost the Deanship, despite his efforts to swing the election by summoning only those who he thought would vote for him.

Of Andry's personal life we have little knowledge. He was married three times, and had one daughter by his third wife. He remained active professionally until his death in 1742, at the age of eighty-four years.

It is strange that, despite a considerable volume of information on the life and personality of Andry, we know almost nothing of his physical characteristics and personal appearance. No picture of Andry has been found at the College of Grassins, where he was Professor of Theology, or at the Church of Saint-Roch, where he was buried. No picture has been found in his numerous works at the Library of the Faculty of Medicine in Paris, although it was the custom of the period for the author's portrait to be used as a frontispiece. It was also customary for each dean of the faculty of medicine to have his portrait engraved on a medallion, and, according to Mauclaire, reference to such a medallion has been found in a publication of 1858; nevertheless, the actual medallion has never been located. In 1869, Chéreau [9] stated that a magnificent portrait of Andry was at that time displayed in one of the rooms of the Faculty of Medicine in Paris. In 1937 Bonola [6] wrote that six fine portraits, which, judging from the large wigs, ermine capes, and black caps, depicted men of Andry's time, had been located; but that their names and the dates had been lost during the Revolution and they had become known as "the Six Anonymous". Mauclaire believed that "Anonymous Number Three" (Fig. 9) represented Andry.

FIG. 9

FIG. 10

Fig. 9: Portrait at the Faculty of Medicine in Paris, possibly representing Andry.
Fig. 10: Caricature of Andry attacking the shop of a barber-surgeon.

Bonola [7] tells us that, in this portrait, François de Troy, one of the most famous portrait painters of the period, shows us a somewhat youthful and keen face with a full serene forehead, untouched by wrinkles, penetrating eyes, and a subtle ironic smile. On the whole it is difficult to reconcile this picture with the age of Andry, which was eighty at the time at which the picture is dated, especially when Andry's life had been "a constant battle". There are other discrepancies, such as the absence of a Cavourian beard, the date of the painting—twelve years after Andry lost the deanship—and the fact that no mention of this portrait is made in catalogues of François de Troy's works. These discrepancies have led Bonola to conclude that the portrait cannot be accepted without reservations.

The only known pictorial representation of Andry is a caricature (Fig. 10), which has been found at the Bibliothèque Nationale. According to Delaunay, there were two variants of this etching. Andry is represented in the act of trying to destroy the shop of a barber-surgeon by kicking at it and tearing down its sign. He appears to be a slender man of moderate height, full of energy and anger.

How are we to evaluate this colorful person? Of Andry's ability there is no question. He is said to have been a man of great talents, sound knowledge, and brilliant imagination. He has been described also as meddlesome, quarrelsome, abusive, jealous, full of low intrigues and mean passions, a grudger, and no amiable character. It may be that, as suggested by Bonola[6], our information has been prejudiced by criticism emanating from Andry's wounded adversaries. Apparent in every biography of Andry, however, is the striking combination of professional merit and personal disrepute.

Andry's influence upon orthopaedic surgery is perhaps less difficult to assess. He has been called the father of orthopaedics and the author of its first textbook; however, these designations apply only in so far as the term itself and the non-surgical orthopaedics of childhood are concerned. As pointed out by Mercer, Andry "taught orthopaedics as a branch of preventive medicine, rather than as an off-shoot of surgery". Most apt is Putti's designation of Andry as the *vecchio padrino* (old godfather) of orthopaedics.

It is important that, by his very attacks upon the surgeons of his day, Andry may have exerted a most constructive influence on the development of surgery and its specialties. To appreciate this, we must realize that in Andry's time the standards of surgical education and practice were far inferior to those of medicine. In France the battle between

qualified surgeons and their medical confreres, on the one hand, and the uneducated barber-surgeons, on the other, had raged for more than a century. In England an act to separate qualified surgeons from barber-surgeons was passed by Parliament three years after Andry's death[12]; in France a decree reconciling physicians and surgeons was issued by the Convention in 1794[15].

Finally, to return from this glimpse of the past to our problems of today, what can modern orthopaedic surgeons learn from Andry? He would be the first to agree that, the better the surgeon, the less often he finds surgery necessary. We have all become surgeons and debate techniques of treatment; how much more effective would be an increased knowledge of prevention. We know how to reduce a fracture, but not what makes it heal; how badly we need a pioneering imagination in research! The greatest lesson from Andry is to preserve for our beliefs and practices his spirit of sharp questioning and criticism. Only thus can we hope to separate truth from fallacy, keep our house in order, and contribute to the further growth of orthopaedic surgery.

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REPORTS OF THE VISIT TO GREAT BRITAIN OF ORTHOPAEDIC SURGEONS FROM THE UNITED STATES AND CANADA

On March 17, our group of fifteen sailed from New York on the Queen Mary. There were ten Americans: L. Ramsey Straub of New York, J. Hamilton Allan of Philadelphia, Carroll B. Larson of Boston, Hugh Smith of Memphis, Benjamin E. Obletz of Buffalo, John J. Fahey of Chicago, S. Benjamin Fowler of Nashville, William H. Bickel of Rochester, Minnesota, Verne T. Inman of San Francisco, and Donald W. Blanche of Los Angeles. There were also five Canadians: Frank Patterson of Vancouver, William B. MacKinnon of Winnipeg, F. P. Dewar of Toronto, Roger Gariepy, and Leo Walker of Montreal. The crossing was made with clear weather and on a calm sea.

When the ship docked at Southampton, we expected someone to meet us, but were astonished to be greeted by a group of five members of The British Orthopaedic Association, who came aboard, had dinner with us, and then, through a prearranged plan, got us off the ship and through customs in the least possible time. We were then escorted by train to London and to the Cumberland Hotel.

The next evening representatives of The British Orthopaedic Association gave a welcoming banquet. This initial reception proved to be typical of the planning and hospitality that was in store for us on the entire trip.

We stayed in London the first week, visiting seven hospitals. At each hospital visited, a full and very interesting program had been planned, with subjects presented by various members of the orthopaedic staff, often with the cooperation of the departments of medicine, general surgery, x-ray, and pathology. The surgeon presenting a subject had it well prepared and, in many instances, illustrated his points with ingenious models or diagrams, then showed patients. These were usually out-patients, many no longer under active treatment, who willingly came to the clinic at the request of their surgeon. We were impressed throughout the trip by the faith of the patients and gratitude shown for their surgeons.

Most of the hospitals are centuries old, with a rich historical background, and with names familiar to us from the literature. It was most inspiring to walk in these halls through which so many great men have passed and in the libraries and museums to see the handwritten manuscripts and the pathological specimens prepared by them.

The old city of London was very severely damaged by bombing, and a great deal of this has not yet been cleared away. In the rest of London, the bomb damage is much less evident, but there are many vacant lots where buildings once stood, and many buildings which appear relatively normal from the outside are completely gutted within. Several of the hospitals had suffered from bombing. There is so much repair work to be done that there is relatively little new construction being carried on.

The remainder of the trip was made in a chartered bus in which we traveled the length and breadth of England, and into Scotland, a total of 2400 miles, visiting thirty-three hospitals and six rehabilitation centers. In the country districts, many of the hospitals are of simple one-story construction of large wards, one side being entirely open, or closed only by folding doors or curtains. In many, the beds are mounted on large wheels to facilitate moving into the open. The patients in these wards appeared particularly healthy and cheerful. Many of the hospitals have their own brace shops. The operating rooms are almost uniformly of ample size, and constructed for efficiency of use and of cleaning. There is a general shortage of hospital beds, and also a shortage of nurses; so that there is considerable delay in admission of elective cases to the hospitals. We were impressed by the ability of the orthopaedic nurses, who, after the completion of their regular training period, are given additional training in the care of the orthopaedic patient and are therefore invaluable, not only in the treatment of hospital patients, but also in working in distant diagnostic and follow-up clinics, and in making contacts with patients in their homes.

In general, the types of orthopaedic cases seen in the wards of the British hospitals were similar to our own, except that there was a much higher incidence of bone and joint tuberculosis. It is impossible to make sweeping statements concerning the surgical care and to compare it with our own, because, as in America, opinions and methods vary from hospital to hospital, or even from service to service within one hospital. It seemed to us that in general the treatment was similar to corresponding hospitals in our country, without a great deal of variance between the average British and average American center. In fact, it was when the various members of our group discussed a surgical problem that the widest diversity of opinion was expressed. There is a tendency to segregate cases in special centers, where, through study and experience, knowledge and skill can be obtained in treatment of this particular problem.

In a number of hospitals, hand injuries were segregated and this problem was placed under the supervision of one surgeon. The methods of tendon surgery were not essentially different from those commonly practised in this country, or in other parts of Britain, but it was in these special centers that the best results were seen, attributable to greater skill and experience.

Under the impetus of the recent War, centers were set up for treatment of peripheral-nerve injuries. At the onset, there were few surgeons in Britain trained or especially interested in this group of patients, and

their care gravitated to the orthopaedic surgeon. Through the development of special centers, a great deal has been learned and peripheral-nerve injuries have become generally recognized as within the scope of the orthopaedic surgeon. Uniform standards for grading end-results have been agreed upon, so a more accurate follow-up can be carried out and results appraised.

Patients requiring amputations are sent to centers which are set up to provide complete care for surgery, fitting of prostheses, and training in their use, with close cooperation between surgeon, limb fitter, and rehabilitation counsellor. After a patient has been fitted, he is trained in the use of the appliance, be it for upper or lower extremity.

Throughout Britain, much interest is being shown in the problem of the arthritic hip, with argument between the proponents of arthrodesis and arthroplasty. During our tour, approximately ten different types of hip arthrodesis were presented, some intra-articular, some extra-articular, some combined, and with considerable enthusiasm for metallic internal fixation. In the same hospitals, Vitallium-mold arthroplasties were being done frequently, and we were shown some excellent results; although, in most instances, the patients were still in their recent postoperative period. For the hip with intra-articular infection, such as tuberculosis, the ischiofemoral arthrodesis was found to be popular. In most instances, this was performed through a simple lateral approach, although there seemed to be a growing tendency to operate through a posterior incision under direct vision.

In treatment of bone and joint tuberculosis, conservatism is the watchword. It is believed that tuberculosis is a generalized disease and the local lesion is only one phase; therefore, the patient needs long sanitarium care at bed rest, no matter how the local lesion is treated. Spine lesions are treated in recumbency on a Jones frame or a plaster bed until the lesion is quiescent (at least eighteen months in adults, and longer in children). The patient is then fitted with a brace and is allowed up. It is believed that the spine will fuse spontaneously in most cases, and surgical fusion is necessary only in a small percentage. In former years, earlier fusion operations were done; but studies showed that the period of treatment was not shortened, and there were more complications. Patients with paraplegia have in the past been treated conservatively, and still are, in some hospitals, although in most centers visited, surgical anterolateral decompression of the spinal cord through a costo-transversectomy approach is now advised, if the patient does not make rapid response under conservative treatment. Patients with tuberculosis of the hip are generally treated with a long period of rest on a Jones frame or similar apparatus; then, after fibrous ankylosis has been secured, an extra-articular fusion may be done. The supply of streptomycin is so limited that its use is confined to the desperate case, such as tuberculous meningitis.

Inequality of limb length in children is a rather frequent complication of tuberculosis and osteomyelitis. This problem is solved in most instances by limb-lengthening procedures, and we saw some excellent results. Shortening of the opposite extremity is rarely done, and we saw no instances of surgical epiphyseodesis.

In fracture treatment in general, considerable emphasis is being placed on early function and minimum immobilization. Spine fractures are common in the coal-mining districts. In some mines, the seams are narrow and the ceilings so low that the miners work in a flexed position; thus they are particularly vulnerable to spine injuries in cave-ins. Most surgeons adhere to the principle of reduction of simple compression fractures by hyperextension followed by plaster-cast immobilization. However, there is a strong belief in several centers that the simple compression fracture need not be reduced or immobilized, deformity of a vertebral body not being considered to be the cause of future disability. They also believe that the hyperextended position is the cause of subsequent lumbosacral back pain, and immobilization the cause of joint stiffness.

Fractures of the femoral shaft are almost uniformly treated in traction on a Thomas splint, unless satisfactory position cannot be obtained, or some other fracture is present, demanding open reduction. Then, in suitable cases, the Küntscher nail is being used. Fractures of the neck of the femur are universally treated by internal fixation, almost always with the three-flanged nail. In the majority of the hospitals visited, internal fixation of intertrochanteric fractures by means of a blade-plate is recommended when practicable; although, in some hospitals, traction is considered to be the treatment of choice.

There was considerable interest manifested in fractures of the os calcis, and in several centers, open reductions were being tried, and the results compared with those treated conservatively with no reduction or immobilization, but with early active exercise. While the numbers of cases were small, the impression obtained was that the appearance of the foot was better after surgery, but function was not improved, good functional results being obtained by either method.

Patients with tentative diagnoses of rupture of a lumbar intervertebral disc are in most instances given a trial at conservative treatment of rest and immobilization. Those who do not respond are operated on by the orthopaedic surgeon for removal of the disc, but in most instances a fusion is not done. Contrast myelography is not uniformly carried out as an adjunct to diagnosis.

One other subject should be mentioned, — rehabilitation, which has received much more attention in England than in America. In general, rehabilitation centers can be grouped into three types. First, there is the type where the injured man is put back to productive work at the earliest possible time, while wearing a dressing or cast. There is a separate building on the factory grounds where regular production machines may be adapted to the capability of the patient; and, as convalescence progresses, the hand grip or foot treadle of the machine may be altered so as to give appropriate exercise to the injured part. Almost any patient who

is ambulatory is put to some type of work. Recovery is more rapid, periods of loss of work are greatly diminished, and the morale of the worker is enhanced by this procedure. This plan exemplifies a new social outlook. Management and labor work together closely; the individual assumes chief importance, and his work and place in society is not changed by his illness or injury.

The second type of rehabilitation center is for those patients who have been so severely injured that they will be unable to return to their former type of work, or for those congenitally handicapped persons who have never been able to work or support themselves. Here the individual is taught a trade by a skilled craftsman, whose goal is to train the cripple in both skill and speed so that he can compete successfully with the normal workman. The subtle training in mental and personal physical readjustment necessary to daily living is learned along with the vocational training, and it is for this phase principally that the resident school is preferable to the day school. For those individuals who are so severely crippled that they cannot compete on the open labor market, permanent residence and sheltered employment is provided, but here again the emphasis is on real production and self support, rather than on the custodial care so often doled out in this country.

The third type of rehabilitation center is set up principally to aid in recovery of such persons as miners who have had spine fractures or other injuries necessitating long periods of disability, and who need physical reconditioning before returning to work. In these, the emphasis is on gymnasium work, games, and outdoor physical labor.

The Spring Meeting of The British Orthopaedic Association came at the end of our first month in Britain. By this time we had become acquainted with many of the surgeons. One half day was spent at one of the large suburban hospitals where over a hundred out patients and many in patients were assembled for examination. There was a concise history and series of x-rays with each patient, so that the individual surgeon could examine and study them at will. At the scientific meetings, one was impressed by the very able presentations, almost all talks being given without any reference to notes. Four of our group were invited to present papers.

At the various centers visited, the local surgeons met us for a social evening, often in their own homes. Everyone was most hospitable and spared no effort to entertain us and make us feel welcome. It was at these informal gatherings that we learned much of the ordinary customs and opinions of the British people, and could discuss various medical problems. At every center we were honored by a banquet, attended by all of the local orthopaedic surgeons, and many of the hospital consultants representing other specialties. Many of the districts visited were interesting historically, and after the day's hospital rounds had been finished, we visited castles, cathedrals, country churchyards, beautiful gardens, and historical monuments.

In Scotland we each obtained a tartan waistcoat of our own, or fancied, clan, and adopted them as the badge of our group, to be worn at future reunions.

All of the traveling orthopaedic surgeons from the United States and Canada were most grateful for the opportunity of visiting Great Britain. It is the hope of both our group and the British group who last year came to America, that reciprocal visits may continue in the future. We learned a great deal about the scientific aspect of orthopaedic surgery. We learned much of the historical background and culture of the British people, without which it is impossible to understand their philosophic and political outlook. We became acquainted with many British surgeons, which was perhaps most important of all, for it is through such friendships and understanding that medicine on both sides of the Atlantic will prosper.

Donald W. Blanche, M.D.,
Los Angeles, California

Being most enthusiastic about our visit to Great Britain, I wish to plead for other contemporary orthopaedic surgeons on both shores of the Atlantic, who have not yet had an opportunity equal to ours, that traveling group fellowships be continued as part of the educational program of our senior orthopaedic societies. I know that I speak with the wholehearted approval of all those who have shared in this exchange.

It is significant that the average age of the Fellows is approximately forty years. These men have completed their formal training, are firmly fixed on the paths of orthopaedic surgery, and will succeed to positions of increased responsibility and leadership in their own centers. That participation in such an exchange adds greatly to their knowledge and resources is undisputed, and it follows that their value to their centers will be augmented by this experience.

The dissemination of knowledge is difficult within our own borders and international transmission is doubly so. *The Journal of Bone and Joint Surgery,* this excellent intermediary, has done much to remedy the situation, but written words are no substitute for experience. The untraveled reader is always confronted with the impossibility of fitting the paper to its locale and to the personality of its author. The unknowing cannot advise wisely regarding overseas educational opportunity, nor do friendships spring easily from scientific treatises.

Strong mutual ties flourished during World War I with the advent of North American surgeons to hospitals in Britain. Friendships resulted, many of which are still vigorous, and until the present these have been the mainsprings of our common interests. The widespread battle fields of World War II, scattering the spe-

cialists, opposed the continuity of this tradition and many orthopaedic surgeons now destined to teach find themselves limited in knowledge of their contemporaries overseas.

Occasional visits of distinguished people, whose activities are necessarily limited to a very high level, and sporadic interchange of junior men in training will not develop the desired degree of international understanding. Groups, traveling under the guardianship of the Orthopaedic Associations, present this potential; for it should be possible to enlist one man from each center of orthopaedic surgery. Organized tours to the centers famous for their work have other advantages; they enable the host to recall many out patients, who would otherwise not be seen, for the purpose of demonstrating long-term end-results. Discussion too, is enhanced, for the traveling group can usually supply one individual better versed than the remainder in the subject under debate, and this participation fosters respect and friendship among the group itself.

Such a program is not feasible without the continued and enthusiastic support of all the senior orthopaedic surgeons in our three countries, who may take pride in their leadership. With few exceptions, men of our age group could not afford a like journey in spite of the obvious advantages. The first reciprocal exchange has been accomplished by the personal generosity of members of our Orthopaedic Associations, assisted by grants from the Nuffield Foundations, and we are most grateful. It is hoped that other Foundations interested in postgraduate education will be stimulated by the success of this first venture to make possible further traveling group fellowships.

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ELLIS WILLIAM JONES

1884–1948

Orthopaedic surgery in the Southwest is relatively a new specialty. In 1913, there were not more than two orthopaedic surgeons in Los Angeles, and none in the outlying communities. Ellis Jones came into this field after a thorough training in Eastern Centers and in Europe. A man of unlimited energy and enthusiasm, he threw himself into his chosen work. An Orthopaedic Clinic was developed at the Children's Hospital, and others in Santa Barbara and Long Beach. Not only was care furnished to the needy, but interest in orthopaedic surgery was stimulated in young men by his teaching.

Ellis William Jones was born in Wales, and shortly thereafter came to Virginia with his parents. He received his education in Boston, graduating from Harvard University in 1906, and Harvard Medical School in 1910. After internships at Massachusetts General and Peter Bent Brigham Hospitals, and a Residency in Surgery at Waterbury Hospital in Connecticut, he became an assistant to the late Fred H. Albee in New York. After completing his training with Dr. Albee, Dr. Jones spent six months with Sir Robert Jones in Liverpool, who invited him to remain as an associate in practice.

Dr. Jones made many valuable contributions to medical literature, among them *The Operative Treatment of Irreducible Paralytic Dislocation of the Hip Joint, Synovectomy of the Knee Joint in Chronic Arthritis, Operative Treatment of Chronic Dislocation of the Peroneal Tendons,* and *Trochanteric Transplantation in the Treatment of Fractures of the Neck of the Femur.*

In 1937, Dr. Jones was a guest of the British Medical Association at Belfast, and presented a paper, *Fracture of the Neck of the Femur.*

He had a great interest in surgery of the knees and hips, and his work in this field was quite remarkable.

Dr. Jones was a member of many California Medical Associations, the American College of Surgeons, The American Orthopaedic Association, The American Academy of Orthopaedic Surgeons, The International Orthopaedic Society, American Medical Association, and the Cancer Research Association. To all of these organizations, he contributed generously of his time and ability.

Dr. Jones was married February 28, 1914, to Elizabeth Bradley, who survives him, together with two sons, Dr. Ellis Jones, Jr., of Pasadena, and Harvey Bradley Jones of Los Angeles, California.

Dr. Jones was a surgeon of unusual ability, a man of pleasing personality. He attracted people and made friends in all walks of life. His sincerity of purpose and interest in humanity provided many a hopeless cripple with the will to recover. As he strides on down the corridor of time, his shadow will ever lengthen, and his contributions to suffering humanity become more manifest.

R. NELSON HATT

1889–1949

Dr. Rafe Nelson Hatt, aged fifty-nine, died of coronary thrombosis in his home, 2620 Anuenue Street, Honolulu, T.H., Friday morning, May 27, 1949. Able, genial, lovable, Nelson Hatt will be mourned by many and, not the least, by the young men and women who, as children, benefited by his skillful and kindly ministrations.

Born in West Paris, Maine, on November 11, 1889, he received his early education there, prepared for college at Bridgeton Academy in Harrison, Maine, and was graduated from Colby College in 1914. Following his graduation from Tufts Medical School in 1918, he served his orthopaedic internship at the Massachusetts General Hospital in Boston. Continuing at the same hospital, he held the posts of Assistant in Orthopaedics and Assistant Surgeon to Out Patients, at the same time carrying on an orthopaedic practice in Boston.

During his years at the Massachusetts General Hospital, he made such rapid strides in orthopaedic surgery that the man under whom he studied, Dr. Robert B. Osgood, strongly recommended his appointment as Surgeon-in-Charge of the Mobile Unit of a Shriners' Hospital for Crippled Children, then about to be established in Honolulu. Before accepting the post, Dr. Hatt visited the famous Scottish Rite Hospital for Crippled Children in Atlanta, Georgia, the model upon which the Shriners' Hospitals were patterned, where he was further inspired by the great work of Dr. Michael Hoke. He accepted the Honolulu post and assumed charge there in December 1922. He organized the Honolulu Unit at Queen's Hospital under great difficulties. His achievements in this field were so marked that, shortly before the completion of the New England Unit of the Shriners' Hospitals at Springfield, Massachusetts, he was recommended by the Shriners' National Advisory Board of Orthopaedic Surgeons as the man best suited to take charge of the Springfield Unit. He reluctantly left Honolulu in November 1924, after almost two years in the Hawaiian Islands, and, on December 24 of the same year, took charge of the nearly completed Springfield Shriners' Hospital.

In August 1942, Nelson Hatt entered the Army Medical Corps in World War II. He went overseas immediately following the invasion of Sicily in 1943, and was a front-line surgeon during the strenuous days of the first landings on the southern front of Europe. Due to a knee injury received in line of duty, he was returned to the United States in May 1944; he was assigned to the Thomas England General Hospital in Atlantic City as Chief of the Orthopaedic Service. Later he was stationed at the Cushing General Hospital in Framingham, Massachusetts, as Chief of Orthopaedic Surgery.

He had had a very difficult time making the decision to leave his work with the crippled children to serve with the Army and his assurance that he had made the right decision came in a letter sent to a friend in Springfield, written while he was with the troops in Sicily.

> "I am getting a kick out of this service and I have long since ceased to wrestle with my conscience for having deserted one of the most important jobs on earth, a crippled child," he wrote. "Here I have an opportunity to send the Jones's kid or the Brown's only boy back alive or to save an arm or leg for Junior Smith. It may sound a bit strange, but the same service to Karl Heinrich or Guiseppe Biorni has been gratifying too."

After leaving the Army Medical Corps in 1946 with the rank of Lieutenant Colonel, Dr. Hatt returned to the post of Chief Surgeon of the Shriners' Hospital in Honolulu, which he had left when he accepted the position in Springfield in 1924. He continued to serve in this capacity until his death.

He was honored by his colleagues in the medical profession in Springfield with his election to the Presidency of the Springfield Academy of Medicine in 1939. The following year he was appointed by Governor Leverett Saltonstall to a five-year term as member of the Massachusetts Public Health Council. He was the recipient of the Pynchon medal, awarded annually in Springfield for outstanding service to the community. In 1938, at its commencement program, his Alma Mater, Colby College, presented him with an honorary degree of Master of Arts. He was a 32nd degree Mason, and was a member of the American Medical Association, The American Orthopaedic Association, The American Academy of Orthopaedic Surgeons, the Forum Orthopaedic Club, the American College of Surgeons, and the New England Surgical Society.

Among his contributions to literature are: *The Central Bone Graft in Joint Arthrodesis, Some Orthopaedic Gleanings from a Neurosurgical Center* etc. Two papers, *A Twenty-five Year Follow-up of Tuberculosis of the Spine* and *Observations on Muscle Transplantation in the Lower Extremity*, were in preparation at the time of his last illness.

He is survived by his wife, Dr. Ednah Swasey Hatt; a son, Dr. William Hatt, an intern in the Queen's Hospital, Honolulu; and two daughters, Mrs. Mary E. Box of Salem, Massachusetts, and Constance Hatt, a student at the Punahau School in Honolulu.

The memory of Nelson Hatt will remain indelibly inscribed in the minds of those who knew him or who have had the privilege of coming in contact with him. His fine fellowship was a boon to many an old and many a new friend. His service to every community in which he lived was not only gladly and graciously given, but was of lasting value. He led a full life, a genial one, and gave all he had each day. To quote Dryden as a fitting epitaph—

> "Happy the man, and happy he alone,
> He who can call today his own;
> He who, secure within, can say,
> Tomorrow, do thy worst, for I have lived today."

News Notes

The Seventeenth Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held in New York City, February 11–16, 1950. Headquarters will be at the Waldorf-Astoria.

Dr. Robert I. Harris, of the University of Toronto, has been awarded Honorary Fellowship in the Royal College of Surgeons of England. The Council made him Hunterian Professor; his Hunterian Lecture, delivered on April 29, was on the subject "Spondylolisthesis".

In the list of new Fellows elected to **The American Academy of Orthopaedic Surgeons,** published in the April issue of *The Journal,* the name of Dr. Carmelo C. Vitale of Brooklyn, New York, was inadvertently omitted.

The Washington Orthopaedic Club, at its meeting on May 23, 1949, elected the following officers for the coming year: President, Dr. Milton C. Cobey; Vice-President, Dr. Thomas Foley; Secretary-Treasurer, Dr. Everett J. Gordon.

Word has been received of the election of the following officers for the year 1949–1950 of the **Sociedad Nacional de Cirugia** (Cuba): President, Dr. José Lastra Camps; Vice-President, Dr. Manuel Costales Latatú; Secretary, Dr. René Smith; Vice-Secretary, Dr. Luis Rodríguez Baz; Treasurer, Dr. Antonio Rodríguez Díaz; Vice-Treasurer, Dr. Tomás Armstrong.

Announcement is made of the organization of the **Association of Bone and Joint Surgeons.** The organizational meeting was held in Oklahoma City, Oklahoma, April 1 and 2. Dr. Earl D. McBride of Oklahoma City was chosen President for the first year, and Dr. Fritz Teal of Lincoln, Nebraska, Secretary. It is expected that the meetings will be held annually, and that the organization will be national in scope. Certification by The American Board of Orthopaedic Surgery is one of the requirements for membership.

The National Council of the **Kappa Delta Sorority** has inaugurated a prize of one thousand dollars, to be given annually by **The American Academy of Orthopaedic Surgeons,** for the best research in orthopaedic surgery, performed during the year by an individual in the United States. The first award, for the year 1949, will be announced at the Seventeenth Annual Meeting of the Academy in New York, February 11, 1950. Those wishing to compete for this prize may secure further information from the Chairman of the Award Committee for 1949, Dr. Walter Stuck, 1426 Nix Professional Building, San Antonio, Texas.

The American Board of Orthopaedic Surgery, Inc., has announced new officers for the year 1949, as follows:

President, Dr. Allen F. Voshell, Baltimore, Maryland;
Vice-President, Dr. Ralph K. Ghormley, Rochester, Minnesota;
Secretary-Treasurer, Dr. Harold A. Sofield, Chicago, Illinois.

The other members of the Board are:

Dr. J. Spencer Speed, representing the American Medical Association;
Dr. Joseph A. Freiberg, Dr. Guy A. Caldwell, Dr. Francis M. McKeever } representing The American Academy of Orthopaedic Surgeons;
Dr. J. Warren White, Dr. H. Earle Conwell } representing The American Orthopaedic Association.

Some changes in regulations have also been announced. Full information may be obtained by writing to the Secretary, Dr. Harold A. Sofield, 6 North Michigan Avenue, Chicago, Illinois.

The Seventh International Congress on Rheumatic Diseases was held at the Waldorf-Astoria Hotel in New York City, May 30 to June 3. Dr. Philip S. Hench of the Mayo Clinic was Chairman of the General Committee on Arrangements. Dr. Loring T. Swaim served for Dr. Ralph Pemberton, who was unable to be present because of illness. Dr. Pemberton was President of the *Ligue Internationale contra de Rheumatisma,* as well as of the Pan American League for the Study and Control of Rheumatic Disease. These two organizations cooperated with the American Rheumatism Association, of which Dr. Richard H. Freyberg was President, in plans for the Congress.

The Plenary Sessions were held at the Waldorf-Astoria Hotel; the Clinical Sessions were held at Bellevue Hospital, Mt. Sinai Hospital, New York Hospital, Polyclinic Hospital, Goldwater Memorial Hospital, Presbyterian Hospital, Hospital for Special Surgery, Hospital for Joint Diseases, St. Luke's Hospital, Institute of Rehabilitation and Physical Medicine, and University Hospital, New York University. A program of unusual interest was presented.

About one hundred foreign guests were present. A two-week itinerary of various arthritis clinics of the country, following the Congress, was planned for these guests.

The Executive Board of the **American Public Health Association** announces that the Seventy-seventh Annual Meeting of the Association, and meetings of related organizations, will take place in New York, N. Y., October 24–28. The Hotel Statler and Hotel New Yorker will be joint headquarters.

According to an announcement recently made by Dr. E. R. Weidlein, Director of the Mellon Institute, that organization will again join with the University of Pittsburgh's School of Medicine in holding a symposium on orthopaedic appliances at the Institute during the week of September 19, 1949. The First Symposium, which was successful in every respect, has been cited as "a dynamic example of cooperation among scientists, physicians, engineers, and technicians".

The Second Symposium, also sponsored by the Sarah Mellon Scaife Foundation through its multiple Fellowship on Orthopaedic Appliances in the Institute, will be open to invited orthopaedic physicians and surgeons, as well as to selected orthopaedic technologists, skilled in brace design, fitting, and construction. The lecturers will include a number of nationally recognized authorities in orthopaedics, as well as scientists of Mellon Institute. They will give detailed attention to the problems of braces in cerebral palsy, paraplegia, and hemiplegia, resulting from poliomyelitis and other disabling diseases, to scoliosis and related spinal conditions, and to other specialized orthopaedic problems.

Inquiries concerning attendance and program details should be addressed to the **Orthopaedic Appliance Fellowship,** Mellon Institute, 4400 Fifth Avenue, Pittsburgh 13, Pennsylvania.

The National Foundation for Infantile Paralysis, Inc., announces short courses, for physicians, in the diagnosis and treatment of poliomyelitic patients. These short courses are:

Training Center	*Scheduled Courses*	*For Detailed Information and Enrollment, write to:*
Children's Hospital, Boston, Massachusetts	August 15–19	William T. Green, M.D.
City Hospital, Cleveland, Ohio	July 18–23, August 8–13, August 29–September 3	John A. Toomey, M.D. Dept. of Contagious Diseases
D. T. Watson School of Physical Therapy, Leetsdale, Pennsylvania	1–3 weeks, depending on need of each individual. Dates to be specially arranged. Emphasis on when to prescribe the respirator and when the rocking bed, with variations to meet the needs of each patient.	Jessie Wright, M.D., Medical Director
Georgia Warm Springs Foundation, Warm Springs, Georgia	3–6 months, starting October 3	Robert L. Bennett, M.D., Director of Physical Medicine
University of Colorado Medical Center, Denver, Colorado	November 14–19	Winona C. Campbell, M.D., Director of Poliomyelitis Teaching Program

THE AMERICAN ORTHOPAEDIC ASSOCIATION

The Sixty-second Annual Meeting of The American Orthopaedic Association, under the presidency of Dr. Ralph K. Ghormley, was held at the Broadmoor, Colorado Springs, Colorado, May 18 through 21, 1949.

Through the courtesy of the Rocky Mountain Orthopaedic Club, with Dr. Robert G. Packard and Dr. Atha Thomas as chairmen, the members of the Association attended a Clinical Day in Denver on May 17.

The scientific program as presented by the Program Committee follows:

WEDNESDAY, MAY 18

Morning Session

Osteochondromata Arising from Articular Cartilage.
James Vernon Luck, M.D., Los Angeles, California (by invitation).
Discussion: Allan F. Voshell, M.D., Baltimore, Maryland;
Hugh T. Jones, M.D., Los Angeles, California;
J. Albert Key, M.D., St. Louis, Missouri.

Correction of Deformity and Prevention of Aseptic Necrosis in Late Cases of Slipped Femoral Epiphysis.
Edward L. Compere, M.D., Chicago, Illinois;
Clinton L. Compere, M.D. (by invitation).
Discussion: C. Leslie Mitchell, M.D., Detroit, Michigan;
Beckett Howorth, M.D., New York, N. Y.;
Paul B. Magnuson, M.D., Chicago, Illinois;
Harold B. Boyd, M.D., Memphis, Tennessee;
Edward L. Compere, M.D., Chicago, Illinois.

Congenital Dislocation of the Hip with Particular Reference to Its Pathogenesis—Treatment by Open Reduction and Results.
Beckett Howorth, M.D., New York, N. Y.
Discussion: Vernon L. Hart, M.D., Minneapolis, Minnesota (by invitation).

The Trumble Operation for Fusion of the Hip Joint.
George W. Van Gorder, M.D., Boston, Massachusetts.

A New Technique for Arthrodesis of the Hip.
Alan DeForest Smith, M.D., New York, N. Y.;
Orren D. Baab, M.D., New York, N. Y. (by invitation).
Discussion: Carl E. Badgley, M.D., Ann Arbor, Michigan;
Alberto Inclan, M.D., Havana, Cuba.

The Effects of Radio-Activity on Bone.
John Z. Bowers, M.D., Washington, D. C. (by invitation).
Discussion: John R. Moore, M.D., Philadelphia, Pennsylvania;
Joseph S. Barr, M.D., Boston, Massachusetts.

Noon: First Executive Session.

Afternoon Session

A Conference, sponsored and arranged by the Joint Committee on Postgraduate Education of The American Orthopaedic Association and The American Academy of Orthopaedic Surgeons.

1. Introductory remarks by the Chairman.
   A. R. Shands, Jr., M.D., Alfred I. duPont Institute, Wilmington, Delaware.
2. The Ideal Curriculum:
   A. For Adult and Fracture Training.
      Alan DeForest Smith, M.D., New York Orthopaedic Hospital, New York, N. Y.
   B. For Children's Training.
      William T. Green, M.D., Children's Hospital, Boston, Massachusetts.
   C. For Basic-Science Instruction.
      Guy A. Caldwell, M.D., Tulane University, New Orleans, Louisiana.
3. The Ideal Curriculum of Resident Training in:
   A. A University Clinic.
      Carl E. Badgley, M.D., University of Michigan, Ann Arbor, Michigan.
   B. A Private Clinic.
      James S. Speed, M.D., Campbell Clinic, Memphis, Tennessee.
4. Resident Training in a Government Hospital:
   A. Veterans Administration.
      Dana M. Street, M.D., Kennedy Veterans Hospital, Memphis, Tennessee (by invitation).
   B. United States Army.
      Lieutenant Colonel Milton S. Thompson, M.C., Brooke General Hospital, Fort Sam Houston, Texas (by invitation).

5. Special Training the Resident Should Have in:
   A. Cerebral Palsy.
      Robert A. Knight, M.D., Campbell Clinic, Memphis, Tennessee (by invitation).
   B. Infantile Paralysis.
      R. E. Lenhard, M.D., Johns Hopkins Hospital, Baltimore, Maryland.
   C. The Fitting and Making of Braces and Prostheses.
      Atha Thomas, M.D., Denver, Colorado.
6. Special Training the Resident Should Have in:
   A. Related Subjects: Physical Medicine, Roentgenology, Neurology, and Rheumatology.
   B. Research and Publications.
      Fremont A. Chandler, M.D., University of Illinois, Chicago, Illinois.
7. The Graduate School of Medicine Course in Orthopaedic Surgery and Its Curriculum.
   J. T. Nicholson, M.D., University of Pennsylvania Graduate School, Philadelphia, Pennsylvania.
8. What Constitutes a Satisfactory Preceptorship Training.
   J. Albert Key, M.D., Washington University, St. Louis, Missouri.
9. Comments from The American Board of Orthopaedic Surgery on Board Certification and Resident Training.
   Francis M. McKeever, M.D., Los Angeles, California.
10. The American College of Surgeons and Specialty Training.
    Philip D. Wilson, M.D., The Hospital for Special Surgery, New York, N. Y.
11. The American Medical Association and Specialty Training.
    F. H. Arestad, M.D., Associate Secretary of the Council on Medical Education and Hospitals (by invitation).
12. Discussion and Summary.

THURSDAY, MAY 19

Morning Session

The Orthopaedic Treatment of Tuberculosis of the Spine in a Military Tuberculosis Center.
Lieutenant Colonel Harold S. McBurney, Denver, Colorado (by invitation).
Discussion: David M. Bosworth, M.D., New York, N. Y.

Fusion of the Shoulder Joint in Children, Utilizing Autogenous Bone Graft.
Charles R. Rountree, M.D., Oklahoma City, Oklahoma.
Discussion: James Vernon Luck, M.D., Los Angeles, California (by invitation).

Conclusions Concerning the Use of Refrigerated Bone in Orthopaedic Surgery.
Philip D. Wilson, M.D., New York, N. Y.
Discussion: James S. Speed, M.D., Memphis, Tennessee.

Trials and Tribulations in Attempted Femoral Lengthening.
H. Relton McCarroll, M.D., St. Louis, Missouri.
Discussion: LeRoy C. Abbott, M.D., San Francisco, California.

The Congenital Kyphotic Tibia.
Carl E. Badgley, M.D., Ann Arbor, Michigan.
Discussion: Clarence H. Heyman, M.D., Cleveland, Ohio;
Wallace H. Cole, M.D., St. Paul, Minnesota.

Correlation of Myelographic and Operative Findings in Intervertebral-Disc Lesions.
J. Albert Key, M.D., St. Louis, Missouri.

Cauda Equina Tumors as a Cause of the Low-Back Sciatic Syndrome.
James W. Toumey, M.D., Boston, Massachusetts.
Discussion: Joseph S. Barr, M.D., Boston, Massachusetts;
Lenox D. Baker, M.D., Durham, North Carolina.

A Report on the Trip to England of the American and Canadian Orthopaedic Groups.
Donald W. Blanche, M.D., Los Angeles, California (by invitation).

FRIDAY, MAY 20

Morning Session

The Patella: Its Importance in the Derangement of the Knee.
Edwin F. Cave, M.D., Boston, Massachusetts;
Carter R. Rowe, M.D., Boston, Massachusetts (by invitation).
Discussion: Harry C. Blair, M.D., Portland, Oregon.

Acute Non-Tuberculous Psoas Abscesses.
Isadore Zadek, M.D., New York, N. Y.
Discussion: I. William Nachlas, M.D., Baltimore, Maryland.

Giant-Cell Tumors in Children.
Harold D. Palmer, M.D., Denver, Colorado (by invitation).

Factors which Influence Survival in Bone Sarcoma.
C. Howard Hatcher, M.D., Chicago, Illinois.
Discussion: Robert W. Johnson, Jr., M.D., Baltimore, Maryland;
Robert I. Harris, M.B., Toronto, Ontario, Canada.
Circulatory Changes in the Extremities, Associated with Infantile Paralysis and the Relation to the Occurrence of Shortening.
William T. Green, M.D., Boston, Massachusetts;
Thomas Gucker, M.D., Boston, Massachusetts (by invitation);
Margaret Anderson, M.S., Boston, Massachusetts (by invitation).
Discussion: John L. McDonald, M.D., Toronto, Ontario, Canada.
Presidential Address.
Ralph K. Ghormley, M.D., Rochester, Minnesota.

SATURDAY, MAY 21

Morning Session
Restriction of Growth of Bone by Pins through the Epiphyseal Cartilage Plate.
Sylvan L. Haas, M.D., San Francisco, California.
Discussion: Walter P. Blount, M.D., Milwaukee, Wisconsin;
William T. Green, M.D., Boston, Massachusetts;
Gerald G. Gill, M.D., San Francisco, California.
Congenital Metatarsus Varus.
J. Hiram Kite, M.D., Atlanta, Georgia.
Discussion: Harold A. Sofield, M.D., Chicago, Illinois;
Walter P. Blount, M.D., Milwaukee, Wisconsin;
Philip D. Wilson, M.D., New York, N. Y.;
Joseph A. Freiberg, M.D., Cincinnati, Ohio.
An End-Result Study of the Keller Procedure.
Mather Cleveland, M.D., New York, N. Y.;
Edward M. Winant, M.D., New York, N. Y. (by invitation).
Discussion: Samuel Kleinberg, M.D., New York, N. Y.
Ski Injuries—Trauma of Lower Extremities Resulting from Torsion Strain.
John R. Moritz, M.D., Sun Valley, Idaho (by invitation).
Discussion: Atha Thomas, M.D., Denver, Colorado.
Noon: Final Executive Session.

Robert W. Johnson, Jr., M.D., Baltimore, Maryland, is President of The American Orthopaedic Association for the year 1949 to 1950.

At the final Executive Session of this Association, the following officers, members of committees, and delegates were elected:

Officers
President-Elect: James S. Speed, M.D., Memphis, Tennessee.
Vice-President: John L. McDonald, M.D., Toronto, Ontario, Canada.
Secretary: C. Leslie Mitchell, M.D., Detroit, Michigan.
Treasurer: Frank D. Dickson, M.D., Kansas City, Missouri.

Committee Members
Membership Committee: David M. Bosworth, M.D., New York, N. Y.
Program Committee: Walter P. Blount, M.D., Milwaukee, Wisconsin.
Research Committee: James W. Toumey, M.D., Boston, Massachusetts.

Delegate to the American College of Surgeons
Henry W. Meyerding, M.D., Rochester, Minnesota.

Representatives on the American Board of Orthopaedic Surgery
Herman C. Schumm, M.D., Milwaukee, Wisconsin;
Harold A. Sofield, M.D., Chicago, Illinois.

The following were elected to active membership in The American Orthopaedic Association:
Edgar M. Bick, M.D., New York, N. Y.;
Garry deN. Hough, Jr., M.D., Springfield, Massachusetts;
John C. McCauley, Jr., M.D., New York, N. Y.;
Hugh Smith, M.D., Memphis, Tennessee;
Frank Stinchfield, M.D., New York, N. Y.;
Hugh A. Thompson, M.D., Raleigh, North Carolina.